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PRELIMINARY NORMAL YIELD TABLES FOR SECOND-GROWTH WESTERN YELLOW PINE IN NORTHERN IDAHO AND ADJACENT AREAS[1]

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INTRODUCTION

In northern Idaho are large areas of forest land covered with dense, fairly uniform stands of second-growth western yellow pine (*Pinus ponderosa*), varying in age from a few years to 40 or 50 years. For the most part these young stands of yellow pine are found along the foothills of the great forests of the Bitterroot and Coeur d'Alene Mountains, fringing the borders of the fertile and thickly settled prairie lands to the west.

It is desirable to have reliable information upon the quantity of material which these stands will produce in a given period and to know the age at which owners should harvest the crop in order to realize maximum profit. Few stands elsewhere have developed under the conditions which have governed the growth of these young stands. Virgin western yellow pine is practically always many-aged; even-aged stands rarely develop except as a result of cutting. The oldest cuttings in this section are not over 50 years, and hence sources of information as to what these young stands will yield when they reach 70, 100, or 150 years of age are very meager.

The yield tables presented in this paper are compiled from the best material at present available. It is recognized that the results are not conclusive, because of the limited data upon which they are based; yet it is felt that they closely approximate conditions actually existing, and will serve a useful purpose until more comprehensive and reliable figures are available.

MATERIAL AND TECHNIC

Material for the study was obtained, during the author's connection with the University of Idaho, from 83 sample plots in pure even-aged western yellow pine, varying in size from 0.0625 to 0.75 acres. The smallest plots were confined to the younger age classes. The plots ranged from 30 to 163 years in age and represented some of the very poorest as well as some of the best timber-growing soils in the region. The plots were scattered from the vicinity of Moscow, Idaho, on the south, to near Newport, Wash., on the north, and from Fish Lake and a point about 9 miles west of Spokane, Wash., on the west, to Hayden Lake and Harvard, Idaho, on the east.

Because of the scarcity of extensive even-aged stands it was often necessary to take small plots in even-aged groups wherever they

[1] Received for publication June 11, 1928; issued November, 1928.

might be found. The boundaries of the plots were kept within the stand as far as possible, and whenever it was necessary to include the edge of a group in the plot a fair allowance was made for area actually occupied. Surveys were made with staff compass and tape, and, in order to eliminate to a large degree the errors of personal judgment in fixing arbitrary plot outlines, the plots were, with one or two exceptions, kept to a rectangular form.

On each plot a tally was made of all living trees down to 3 inches in diameter at breast height. Diameter and crown class were recorded for each tree. Heights covering the range of sizes present were measured on a sufficient number of trees (usually 8 to 15) to permit the drawing of a smooth curve of height on diameter for each plot or group of plots in the same stand. Form-point heights [2] were measured on 5 to 10 trees on each plot as the basis for assigning the plots to their proper form classes. Age was ascertained by increment borings or stump counts. These measurements were converted to total age by a special study of seedling development, which showed that on an average 4 years are required to reach a stump height of 1 foot and 10 years to reach 4.5 feet, the height at which increment borings were taken.

In the office the total cubic-foot volume of each plot was computed with the aid of form-class volume tables constructed by the author, and based in part upon sample trees cut from plots used in this study. These volume tables show entire wood content of the stem without bark, including tip but excluding a stump of 1 per cent of the total height and also butt swell above this point. Table 1 shows the volumes for form class 70,[3] which will be most generally used for stands less than 100 years of age. Board-foot volumes for each plot were calculated from Show's table for second-growth western yellow pine from the east side of the Sierras in California.[4] This table gives volumes according to the International log rule for ¼-inch saw kerf, with tops utilized to a diameter inside bark of 4 inches.

Other values computed for each plot include:

- Average diameter at breast height.
- Average diameter at breast height of dominant and codominant stand.
- Average height.
- Average height of dominant and codominant stand.
- Total basal area.
- Total number of trees.
- Ratio of board-foot volume to cubic-foot volume.

Average heights corresponding to the average diameters for the stand in question were read from the curves of height on diameter. All the figures were reduced to a per acre basis. The technic of constructing the tables from the material was essentially the same as that developed by Bruce.[5]

[2] The form point is defined as that point in the crown where the wind pressure may be considered as concentrated, which usually will correspond to the center of gravity of the area presented to the prevailing wind. The form-point height is expressed as a percentage of the total height of the tree and is measured very rapidly with the use of a Christen hypsometer divided into 10 equal divisions.

[3] In these tables the trees are classified not only by diameter and height but also by form quotient, which is defined as the ratio between the diameter at one-half the height above breast height and the diameter at breast height. The expression "form class 70" indicates that the form quotient is 0.70.

[4] MUNNS, E. N., and BROWN, R. M. VOLUME TABLES FOR THE IMPORTANT TIMBER TREES OF THE UNITED STATES. PART I. WESTERN SPECIES. p. 135, Table 101. Washington, [D. C.] 1925. (U. S. Dept. Agr., Forest Serv.).

[5] BRUCE, D. A METHOD OF PREPARING TIMBER-YIELD TABLES. Jour. Agr. Research 32: 543-557, illus. 1926.

TABLE 1.—*Volumes*[a] *of western yellow pines of form class 70*[b]

Diameter breast high	Volume of tree whose height is—										
	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	110 feet	120 feet
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
3 inches	0.4	0.6	0.8								
4 inches	.8	1.1	1.4								
5 inches	1.2	1.7	2.1	2.6	3.0						
6 inches	1.8	2.4	3.1	3.7	4.3						
7 inches	2.4	3.3	4.2	5.0	5.9						
8 inches		4.3	5.4	6.5	7.7	8.9					
9 inches		5.4	6.8	8.2	9.7	11.2					
10 inches			8.4	10.1	11.9	13.7	15.6				
11 inches				12.2	14.4	16.6	18.9				
12 inches				14.4	17.0	19.7	22.4	25.2			
13 inches				16.8	19.9	23.0	26.2	29.3			
14 inches				19.5	23.0	26.6	30.3	33.8			
15 inches				22.3	26.4	30.5	34.7	38.7	42.9	47.0	
16 inches				25.3	30.0	34.6	39.4	44.0	48.6	53.5	
17 inches				28.5	33.7	39.0	44.4	49.5	54.8	60.2	
18 inches				32.0	37.7	43.6	49.7	55.3	61.4	67.4	
19 inches				35.5	42.0	48.5	55.3	61.5	68.2	75.0	
20 inches				39.2	46.3	53.6	61.1	68.0	75.4	83.0	90.2
21 inches						59.0	67.4	74.9	83.0	91.5	99.5
22 inches						64.7	74.0	82.2	91.0	100.5	109.0
23 inches						70.7	80.8	89.8	99.5	110.0	119.0
24 inches						76.9	88.0	97.6	108.0	119.0	129.0
25 inches						83.2	95.2	106.0	117.0	129.0	140.0
26 inches								114.0	126.0	139.0	151.0
27 inches								123.0	136.0	150.0	163.0
28 inches								132.0	146.0	161.0	175.0
29 inches								141.0	156.0	172.0	187.0
30 inches								151.0	167.0	184.0	200.0

[a] Based on taper curves by formula $y=\frac{x}{a+bx}$, in which x=distance from tip expressed as percentage of total height above breast height, and y=diameter at distance x from tip expressed as percentage of normal diameter at breast height. Volumes include full stem inside bark from tip to stump of 1 per cent of total height, excluding butt swell.

[b] Form class 70 is generally applicable in second-growth timber less than 100 years old of average density. For open-grown timber reduce values 8 per cent, and for very dense stands or timber over 100 years old increase values 8 per cent.

SITE CLASSIFICATION

Average height of dominant and codominant trees at 100 years of age was used as the basis for site classification. The site index for each plot was determined by reference to a series of anamorphic curves of average height of dominant and codominant trees on total age. In constructing these curves the graduating curve was obtained from plots which, from a preliminary trial, were found to fall approximately between site indices 70 and 100, constituting the most densely populated middle portion of the band of points. The plots representing the extremes in either direction were not included, because it seemed that their distribution was not at all regular over the entire range of ages, optimum sites being found only in younger age classes and poorest sites only in older ages. The site classification curves, showing the distribution of the material by ages and sites and illustrating the technic of anamorphosis used, are given in Figure 1.

The graduating curve shown by the heavier broken line was first drawn to balance the average points of the plots which would fall approximately between sites 70 and 100. The average points and their weights are indicated by triangles. A straight line (*a*) was drawn from the origin to intersect the graduating curve at any convenient point near its outer extremity. A horizontal line (*b*) was drawn from the intersection of the graduating curve and the 100-

year abscissa, taken as the basis for the site classification, to the radial line (*a*), which was also intersected at this point by a vertical line (c), representing the anamorphic position of the 100-year abscissa. A series of straight lines radiating from the origin were then drawn to intersect the anamorphic 100-year abscissa (*c*) at even 10-foot intervals. Only the radiant for the 40-foot site index is shown in the figure. To locate the various site-index curves, vertical lines are drawn for a number of ages, similar to *c*. The intersections of these new age verticals with the site-index radiants are carried over horizontally to the original age verticals, thus defining the points for the final curves. The construction lines, *b*, *c*, *d*, and *e*, *f*, *g*, illustrate

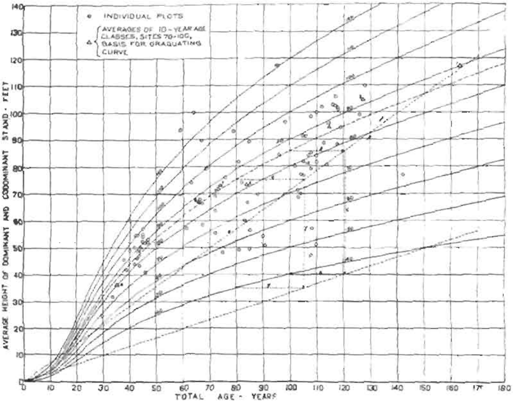

FIG. 1.—Site-classification curves of second-growth western yellow pine. Average height of dominant stand at various ages

the procedure for the 100 and 80 foot points and the 40-foot site-index curve.

BASAL-AREA CURVES AND REJECTION OF ABNORMAL PLOTS

Since total basal area per acre is considered the best basis for testing density of stand, a preliminary series of curves showing basal area per acre for each age and site class was required. Anamorphosis was again used, taking as the basis for the graduating curve only those plots falling between sites 70 and 100. The total basal area of each plot was then compared to the total basal area indicated by these preliminary curves for the given age and site in order to decide whether any of the plots were so abnormal as to justify rejection. Twice the standard error was considered the limit of variability, and this gave a range of about 48 per cent in either direction. Although there were several plots deviating approximately this much

from the preliminary curves, none exceeded it by a significant amount, and it was decided to retain all the plots in the subsequent calculations.

TABLES FOR ENTIRE STAND

Anamorphic curves were drawn showing total basal area per acre, total number of trees per acre, basal area of average tree, total cubic foot volume per acre, and average height of entire stand. For each

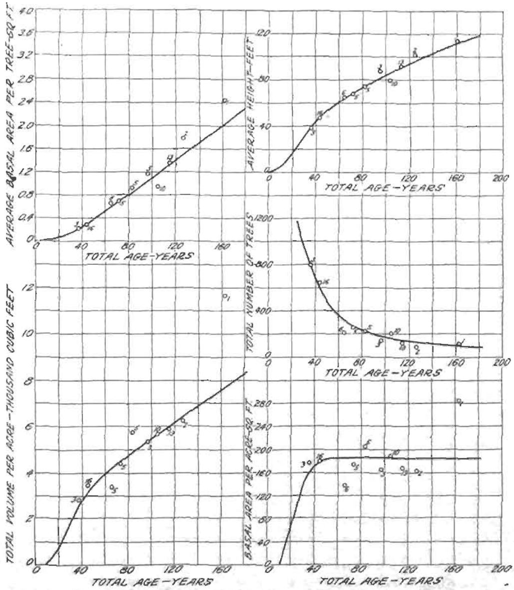

FIG. 2.—Graduating curves for yield tables of second-growth western yellow pine

of these factors the graduating curve was based on the 64 plots between sites 70 and 100. The graduating curves for the various factors were made to check with each other by making the curve for total basal area equal to the product of the curves for basal area of average tree and total number of trees at all ages. The curve for total cubic-foot volume was then made to check with values for total number of trees per acre multiplied by volumes corresponding to trees of average basal area and height from the curves. The graduating curves are shown in Figure 2.

The spacing of the curves for the various site classes about the graduating curves was accomplished by means of "intercept curves." As a basis for these the entire body of data was grouped into 10-foot site classes. Then for each plot a value for each factor was read from the graduating curves corresponding to the age of the plot. For each site group the actual values of each factor were then totaled and divided by the sums of the values read from the graduating curve. These percentage ratios were then plotted over site and

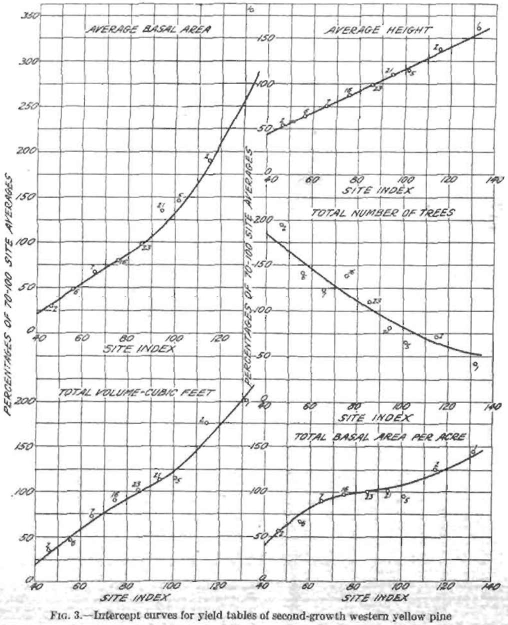

FIG. 3.—Intercept curves for yield tables of second-growth western yellow pine

smoothed intercept curves were drawn, in each case passing through 100 per cent at site 86.8, which represents the average site index of the plots upon which the graduating curves were based. The intercept curves were made to check among themselves in the same manner as the graduating curves. The check on the volume curve was made by using values for the 100-year age. A check of any single-age class establishes a check for the entire range, because the graduating curves, based on age, are already balanced throughout their length. The intercept curves are shown in Figure 3.

By applying the percentages from the intercept curves to the graduating curves, the final series of curves showing values for the various factors on age, by site classes in the conventional form, were obtained. These are shown in Figures 4 to 7 and Tables 2 to 6.

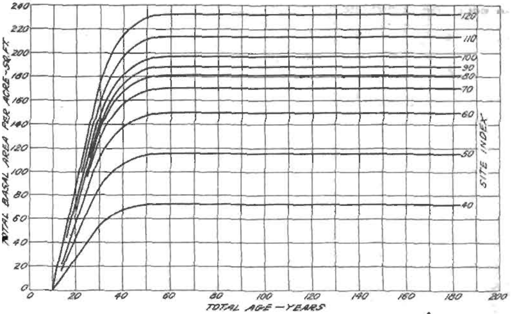

FIG. 4.—Total basal area per acre of second-growth western yellow pine at various ages

TABLE 2.—*Total basal area per acre of western yellow pine*

Age	Basal area of trees at site index indicated								
	40	50	60	70	80	90	100	110	120
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
30 years	55	88	114	130	138	143	150	163	178
40 years	67	107	138	158	169	175	183	198	216
50 years	71	114	147	168	179	186	195	211	230
60–180 years	72	115	149	170	181	188	197	213	232

TABLE 3.—*Total number of trees per acre of western yellow pine*

Age	Number of trees at site index indicated								
	40	50	60	70	80	90	100	110	120
30 years	1,800	1,614	1,438	1,252	1,086	920	792	675	582
40 years	1,246	1,117	995	867	751	643	548	467	403
50 years	892	800	713	621	538	461	393	335	289
60 years	660	592	528	460	398	341	291	248	214
70 years	521	467	416	362	314	269	229	195	168
80 years	427	383	341	297	258	220	188	160	138
90 years	361	323	288	251	218	186	159	135	89
100 years	311	279	248	216	188	160	137	117	98
110 years	274	244	217	189	162	140	118	100	85
120 years	243	218	194	169	146	125	107	91	78
130 years	221	198	176	154	133	114	97	83	71
140 years	202	182	162	141	122	105	89	76	65
150 years	188	168	150	130	113	97	83	70	61
160 years	177	158	141	123	107	91	78	66	57
170 years	166	148	132	115	100	86	73	62	53
180 years	156	140	125	109	94	81	69	59	50

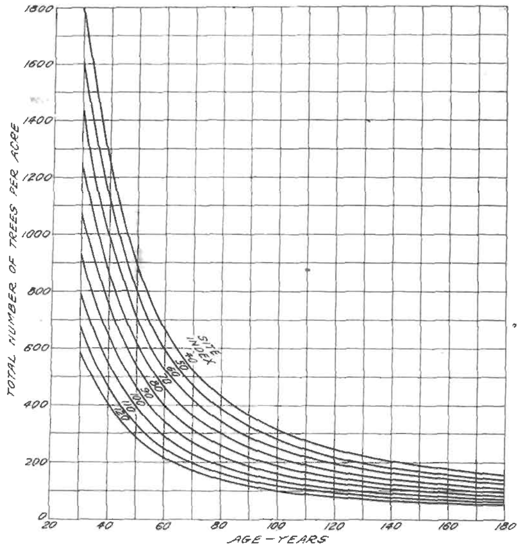

FIG. 5.—Number of trees per acre of second-growth western yellow pine at various ages

TABLE 4.—*Average breast-high diameter of western yellow pine*

Age	Diameter of trees at site index indicated								
	40	50	60	70	80	90	100	110	120
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
30 years	2.4	3.2	3.8	4.4	4.9	5.3	5.9	6.7	7.5
40 years	3.2	4.2	5.0	5.8	6.4	7.1	7.8	8.8	9.8
50 years	3.8	5.1	6.2	7.1	7.8	8.6	9.6	10.8	12.0
60 years	4.4	5.9	7.1	8.2	9.1	9.9	11.1	12.5	14.0
70 years	5.0	6.7	8.1	9.3	10.3	11.3	12.6	14.2	15.9
80 years	5.6	7.4	8.9	10.2	11.4	12.5	13.9	15.6	17.6
90 years	6.1	8.1	9.8	11.2	12.4	13.6	15.1	17.0	19.1
100 years	6.5	8.7	10.5	12.0	13.3	14.6	16.2	18.3	20.5
110 years	6.9	9.2	11.1	12.8	14.1	15.6	17.3	19.5	21.8
120 years	7.3	9.8	11.8	13.5	15.0	16.5	18.3	20.6	23.1
130 years	7.7	10.3	12.4	14.2	15.7	17.3	19.2	21.7	24.3
140 years	8.0	10.8	13.0	14.8	16.5	18.1	20.1	22.7	25.4
150 years	8.4	11.2	13.5	15.5	17.2	18.9	21.0	23.6	26.5
160 years	8.7	11.6	14.0	16.1	17.8	19.6	21.8	24.6	27.6
170 years	9.0	12.1	14.6	16.7	18.5	20.4	22.6	25.5	28.5
180 years	9.3	12.5	15.0	17.2	19.1	21.0	23.3	26.3	29.5

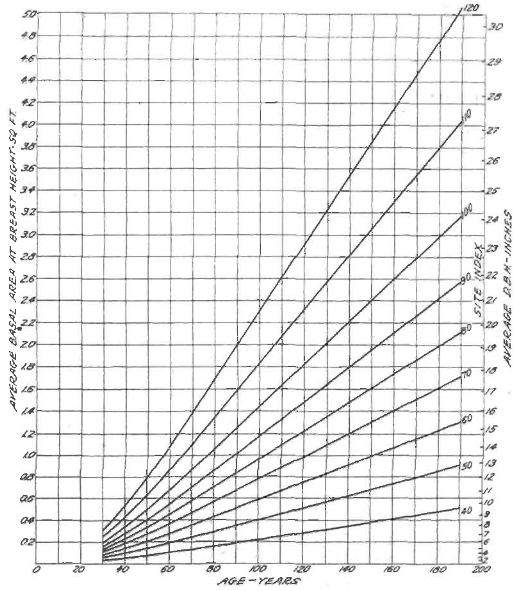

FIG. 6.—Average size of second-growth western yellow pine at various ages

TABLE 5.—*Average height of stand of western yellow pine*

Age	Height of trees at site index indicated								
	40	50	60	70	80	90	100	110	120
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
30 years	13	17	20	24	28	31	35	38	42
40 years	18	24	29	34	39	44	49	54	59
50 years	23	29	35	41	47	54	60	66	72
60 years	26	33	40	47	54	61	68	76	83
70 years	29	37	45	53	61	69	77	84	92
80 years	32	40	49	58	66	75	84	92	101
90 years	34	43	53	62	71	81	90	99	108
100 years	36	46	56	66	76	86	96	106	116
110 years	38	49	59	70	80	90	101	111	122
120 years	40	52	63	74	85	96	107	118	129
130 years	42	54	65	77	88	100	111	123	134
140 years	44	56	68	80	92	104	117	129	141
150 years	46	59	71	84	97	109	122	134	147
160 years	48	61	74	87	100	113	126	140	153
170 years	*50*	*63*	*77*	*90*	*104*	*118*	*131*	*145*	*158*
180 years	*51*	*66*	*80*	*94*	*108*	*122*	*136*	*150*	*164*

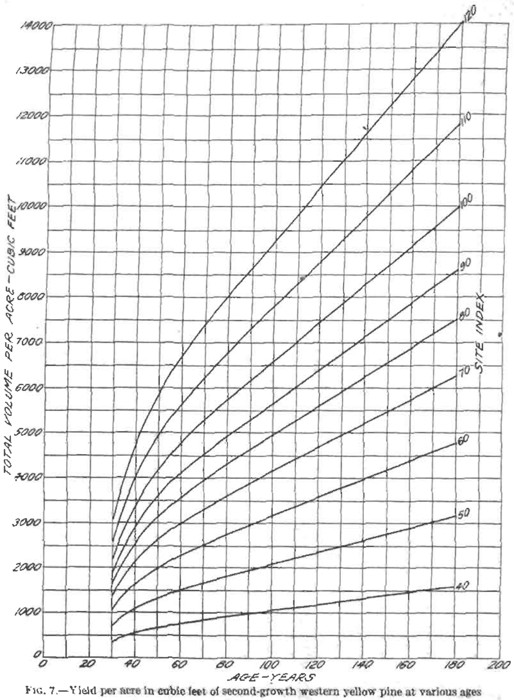

FIG. 7.—Yield per acre in cubic feet of second-growth western yellow pine at various ages

TABLES FOR TOTAL VOLUME IN BOARD FEET

The table showing volume in board feet was derived from the table for total cubic-foot contents by means of the ratios between board-foot and cubic-foot contents. The board foot-cubic foot ratios for all the plots were plotted over average d. b. h.[6] of the stand. This gave a narrow, well-defined band of points through which a smooth curve was drawn. (Fig. 8.)

The ratio for each age and site class was then read from this curve corresponding to the average diameters previously determined. These ratios were applied to the table of total cubic-foot volumes to get the final table of board-foot volumes. The results are shown in Figure 9 and Table 7.

[6] Diameter at breast height (4½ feet).

TABLE 6.—*Total volume per acre in cubic feet of western yellow pine*

Age	Volume per acre of trees at site index indicated								
	40	50	60	70	80	90	100	110	120
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
30 years	350	700	1,050	1,380	1,650	1,880	2,190	2,590	3,080
40 years	550	1,080	1,630	2,140	2,560	2,920	3,400	4,020	4,780
50 years	670	1,330	2,010	2,630	3,150	3,600	4,190	4,950	5,880
60 years	770	1,520	2,290	3,000	3,590	4,110	4,780	5,650	6,720
70 years	850	1,680	2,530	3,310	3,970	4,540	5,280	6,230	7,410
80 years	920	1,820	2,750	3,600	4,310	4,930	5,740	6,780	8,060
90 years	990	1,960	2,960	3,880	4,640	5,300	6,170	7,290	8,670
100 years	1,060	2,100	3,160	4,160	4,960	5,670	6,580	7,790	9,270
110 years	1,130	2,240	3,370	4,420	5,290	6,040	7,010	8,300	9,860
120 years	1,200	2,370	3,570	4,680	5,610	6,410	7,430	8,810	10,450
130 years	1,270	2,510	3,780	4,950	5,920	6,770	7,860	9,310	11,050
140 years	1,340	2,640	3,980	5,210	6,240	7,130	8,280	9,810	11,640
150 years	1,410	2,780	4,180	5,480	6,560	7,500	8,720	10,310	12,240
160 years	1,470	2,910	4,380	5,750	6,880	7,860	9,140	10,810	12,830
170 years	1,540	3,040	4,580	6,010	7,190	8,220	9,560	11,300	13,430
180 years	1,610	3,170	4,780	6,270	7,510	8,580	9,980	11,800	14,020

TABLE 7.—*Total volume per acre in board feet of western yellow pine*

Age	Volume per acre in board feet of trees at site index indicated [a]								
	40	50	60	70	80	90	100	110	120
30 years			140	940	1,850	2,950	4,710	7,200	10,700
40 years		560	2,120	4,260	6,580	9,200	12,900	18,400	25,600
50 years	100	1,810	4,660	8,310	11,910	15,910	21,300	28,600	37,300
60 years	560	3,270	7,330	12,200	17,100	21,800	28,400	36,600	46,300
70 years	1,100	4,750	10,100	16,100	21,900	27,300	34,300	43,000	53,700
80 years	1,610	6,280	12,700	19,800	26,100	31,900	39,300	48,800	60,500
90 years	2,280	7,800	15,300	23,100	29,900	36,000	43,800	54,200	67,000
100 years	2,810	9,340	17,700	26,100	33,200	39,700	48,100	59,400	73,400
110 years	3,400	10,900	20,000	29,000	36,500	43,400	52,500	64,600	79,900
120 years	4,000	12,300	22,100	31,600	39,700	47,000	56,800	70,000	86,500
130 years	4,670	13,800	24,300	34,200	42,700	50,600	61,100	75,200	93,000
140 years	5,320	15,200	26,100	36,700	45,700	54,200	65,300	80,600	99,300
150 years	5,920	16,500	28,000	39,300	48,900	57,800	69,600	85,800	105,900
160 years	6,590	18,000	30,000	41,800	51,900	61,400	74,000	91,100	112,300
170 years	7,280	19,200	31,900	44,200	55,000	64,900	78,300	96,500	118,900
180 years	7,950	20,600	33,800	46,800	58,100	68,600	82,600	101,700	125,500

[a] International rule, ¼-inch saw kerf. Tops utilized to diameter of 4 inches inside bark.

MEAN ANNUAL GROWTH

The mean annual growth in cubic feet and board feet per acre was computed by dividing the figures for total volume by their respective ages. The results are given in Figure 10 and Tables 8 and 9. Mean annual growth affords the most satisfactory index of maturity of the timber by indicating the age at which the average annual growth per acre reaches a maximum. When total volume in cubic feet, regardless of size or quality, is considered, the maximum production is reached between the ages of 43 and 45 years on all sites, with the decline quite slow for the next 20 years. The poorest sites at 40 years of age average only 14 cubic feet per acre per year, while the best sites yield 120. Since the board-foot measure depends upon size as well as total wood volume per acre, and since commercial value is also dependent in large measure on size, the figures for mean annual growth in board feet are of more significance as a guide to management.

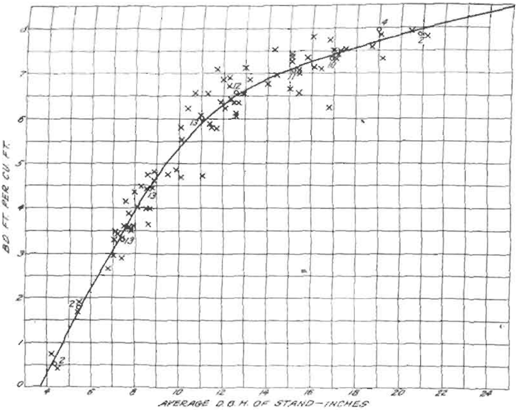

FIG. 8.—Number of board feet per cubic foot of western yellow pine in stands of various average diameters

Maximum mean annual growth is attained on site 120 at 60 years if age, and the period of culmination lengthens as the sites grow poorer, being 150 years for the 60-foot site class and failing to culminate within the limits of the data for the two poorest site classes. On he average site (between 80 and 90) the age of culmination is between 0 and 100 years and this is the period indicated as the most desirable ge at which to cut second-growth western yellow pine.

TABLE 8.—*Mean annual growth in cubic feet of western yellow pine*

Age	Mean annual growth in cubic feet per acre at site index indicated								
	40	50	60	70	80	90	100	110	120
years	12	23	35	46	55	63	73	86	103
years	14	27	41	54	64	73	85	100	120
years	13	27	40	53	63	72	84	99	118
years	13	25	38	50	60	68	80	94	112
years	12	24	36	47	57	65	75	89	106
years	12	23	34	45	54	62	72	85	101
years	11	22	33	43	52	59	69	81	96
0 years	11	21	32	41	50	57	66	78	93
0 years	10	20	31	40	48	55	64	76	90
0 years	10	20	30	39	47	53	62	74	87
0 years	10	19	29	38	46	52	61	72	85
0 years	10	19	28	37	45	51	59	70	83
0 years	9	19	28	37	44	50	58	69	82
0 years	9	18	27	36	43	49	57	68	80
0 years	9	18	27	35	42	48	56	67	79
0 years	9	18	27	35	42	48	55	66	78

TABLE 9.—*Mean annual growth in board feet of western yellow pine*

Age	Mean annual growth in board feet per acre at site index indicated [a]								
	40	50	60	70	80	90	100	110	120
30 years	------	------	4.5	31.2	61.6	98.4	157	240	358
40 years	------	14	53	106	164	230	322	461	639
50 years	2	36	93	166	228	318	426	572	748
60 years	9	54	122	203	284	363	473	610	*772*
70 years	16	68	144	230	312	389	490	*615*	768
80 years	20	78	157	248	326	399	*491*	610	756
90 years	25	87	168	257	332	*400*	487	602	745
100 years	28	93	177	261	*332*	397	481	593	734
110 years	31	99	182	−264	332	394	477	587	726
120 years	34	103	184	*264*	330	391	473	583	720
130 years	36	106	187	+262	328	389	470	578	715
140 years	38	108	−188	262	326	387	466	574	710
150 years	40	111	+*188*	262	325	385	464	+571	706
160 years	41	112	188	262	324	384	+462	570	702
170 years	43	113	188	262	−324	382	460	568	700
180 years	44	114	188	262	323	381	459	565	697

[a] International rule, ¼-inch saw kerf. Tops utilized to diameter of 4 inches inside bark.

The maximum mean annual growth increases from 188 board feet per acre per year on the 60-foot site class to 772 board feet per acre per year for site index 120.

ALIGNMENT-CHART YIELD TABLE

The data in all the tables described above may be presented in compact graphical form for practical use by means of a single system of alinement charts devised by Reineke.[7] Such a chart is shown in Figure 11. The possibility of using this system depends on the fact that values for the various sites represent constant percentages of the average graduating curves for all ages.

On the left of the chart is a series of six scales for age and on the right a corresponding series for site index. Values are read from the central axis for any of the factors by joining the proper age point on a given scale on the left with the proper site-index point on the corresponding scale on the right. Readings on the central scale must be multiplied by 10 for cubic-foot volumes. Board-foot values are not shown directly, but the board foot-cubic foot ratios are obtained by drawing a straight line from the fixed point "P" near the right margin through the average d. b. h. on the central axis, to the scale of board feet per cubic foot. This ratio must then be applied to the figure for total cubic-foot volume.

STAND-TABLE GRAPH

In addition to figures showing total yield and average size, it is of value to be able to estimate the proportion of the total number of trees which will be above any given size, so that value of the yield in terms of special products, such as poles and posts or of timber of specific sizes, can be calculated.

Studies by Baker[8] and Bruce[9] indicate that in even-aged stands the trees are distributed among the different diameter classes in a

[7] REINEKE, L. H. A MODIFICATION OF BRUCE'S METHOD OF PREPARING TIMBER-YIELD TABLES. Jour. Agr. Research 35: 843–856, illus. 1927.
[8] BAKER, F. S. NOTES ON THE COMPOSITION OF EVEN-AGED STANDS. Jour. Forestry 21: 712–717, illus. 1923.
[9] BRUCE, D. Op. cit.

consistent and definite manner for each species. For some species the distribution follows the normal frequency distribution, which is susceptible to definite mathematical treatment. Tests made with the data from the sample plots used in this study indicate that this

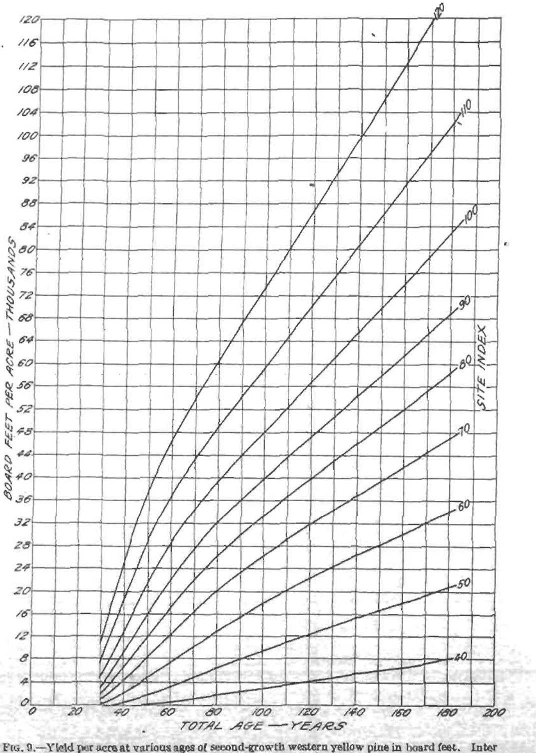

FIG. 9.—Yield per acre at various ages of second-growth western yellow pine in board feet. International rule, ¼-inch saw kerf. Trees 8 inches d. b. h. and up

is true in general for western yellow pine. Bruce has found that the distribution of the various diameter classes about the average is primarily dependent upon the average diameter of the stand, so that this is made the basis for the graphs rather than age and site. Special

coördinate paper is used on which any distribution conforming to the normal frequency will plot as a straight line, the slope of which indicates whether the scatter is great or small.

The plots were first grouped according to their average diameters into 2-inch classes, and for each group a composite stand table was

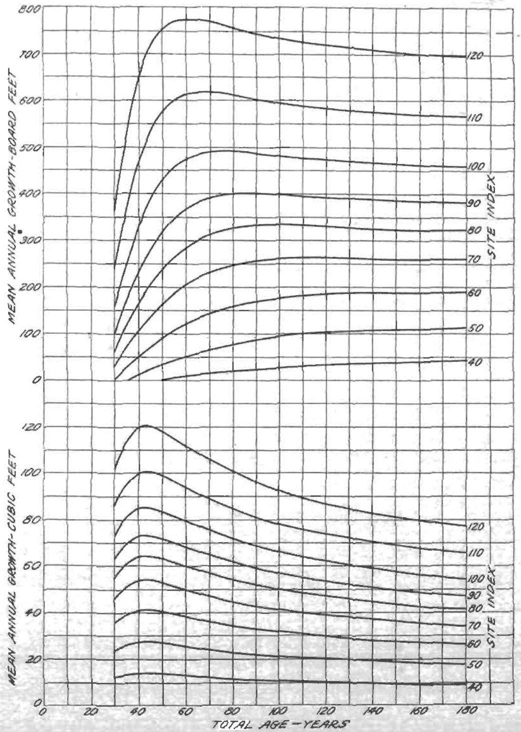

FIG. 10.—Mean annual growth of second-growth western yellow pine in cubic feet and board feet. International rule, ¼-inch kerf

made up. The composite stand tables were then expressed on a cumulative percentage basis, i. e., per cent of total number of trees up to 4 inches, 6 inches, 8 inches, etc. These percentages were

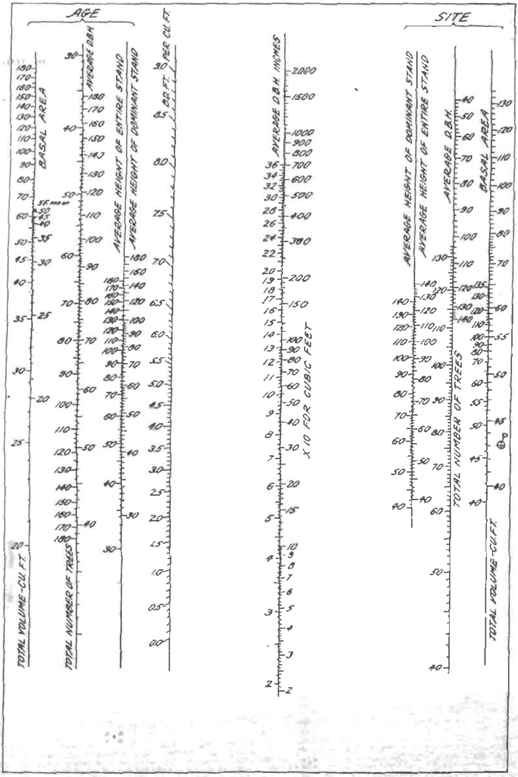

FIG. 11.—Alignment-chart yield table for second-growth western yellow pine. Values for total volume in cubic feet, total basal area per acre, total number of trees per acre, average d. b. h., average height of entire stand, or average height of dominant stand, can be read on central axis by a straight line joining the point for given age on any scale at the left with point for given site index on corresponding scale at right. Board foot-cubic foot ratios are read on board foot per cubic foot axis by a line from fixed point "P" through average d. b. h. for stand in question on central axis

plotted on frequency paper and straight lines fitted to them. The resulting series of lines was harmonized by plotting the intercepts on the 2 per cent and 98 per cent ordinates over actual average diameter of the stand groups and curving the results. From these curves intercepts on the 2 per cent and 98 per cent ordinates can be read off for the even-inch classes, and these values are entered on the final

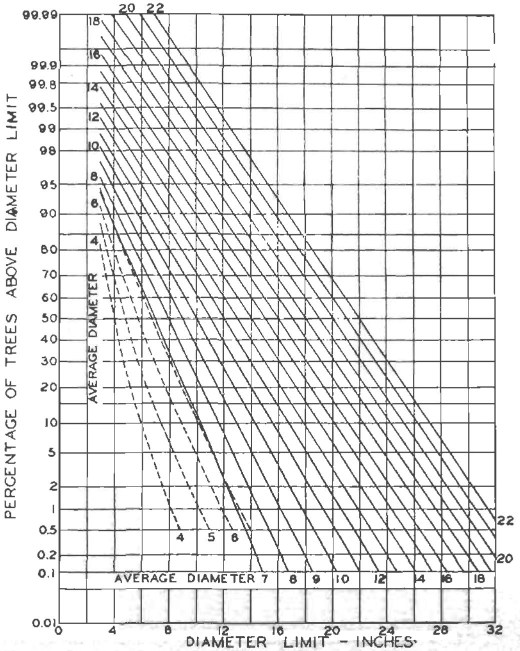

FIG. 12.—Stand-table graph for second-growth western yellow pine, showing proportion of total number of trees above given diameter limit according to the average diameter of the stand

chart. (Fig. 12.) Straight lines joining the intercepts for any diameter class on these two scales represent the frequency distribution of the stands in question.

The straight-line form failed to fit the data in stands below 7 inches in average diameter. In the stands of smaller size there is apparently a higher proportion of the trees below the average than

in a normal frequency distribution. This is doubtless due, in part at least, to the fact that in the field no trees below the 3-inch d. b. h. class were included in the tally. In order to make the chart complete, the distributions for stands averaging less than 8 inches in diameter have been shown as curves, which may be applied with safety to stand tallies in which count is made only of trees 3 inches and over in diameter. The graphical method of presenting stand tables used here was devised by Reineke.[10]

DISCUSSION

It must be borne in mind that the yields shown in these tables represent what may be obtained for areas fully stocked with trees, and that in practice such fully stocked stands are never found over large areas. Yields of large areas are obtained by reducing the tabulated yields in proportion to the degree of stocking of the area in question. At the same time, the tables give conservative figures for fully stocked stands and by no means represent the maximum production which may be obtained under complete protection and careful management. Hardly any of the older plots on which this study is based have been free from fire throughout their lives. Many of them show evidence of having been burned over several times. The effect of fires is to thin out the numbers and at the same time reduce the rate of growth for many years of trees left alive. Thus, could the loss from frequent burning be eliminated, higher yields might be expected at the older ages. Insects and disease, which might be kept at a minimum in a managed forest, have also worked uncontrolled throughout the lives of the stands measured, and evidence of losses from these causes was often at hand.

The somewhat unusual shape of the curves for total basal area is perhaps the direct result of past losses from fire, insects, and disease. Under normal conditions the total basal area per acre might be expected to increase, although at a declining rate throughout the life of the stand. The material upon which this study is based shows no increase in total basal area after about 50 years of age. (Fig. 4.) This may perhaps be explained by the fact that many of the younger plots measured showed no evidence of fire, while practically all the older ones did. A normal increase in basal area may therefore be offset by decimation from fire and other agencies.

Attention should be called to another unusual result obtained in this study, namely, the reverse curvature in the intercept curves for total basal area and total volume in cubic feet. (Fig. 3.) Although studies with other species have generally yielded a simple convex curve for intercepts of total basal area and a straight line for intercepts of total cubic-foot volume, it did not seem possible with the data at hand to obtain a satisfactory check between the various curves without using reverse curvature as shown. To those who object to this unusual spacing of the final curves it may be pointed out that within the limits of the ordinary range of sites encountered in the region the peculiar form of the intercept curves is of no consequence. Very few localities are to be found where the site index is over 105 or less than 55.

[10] Reineke, L. H. Op. cit.

A check was obtained on the final curves for total cubic-foot yields, basal area per acre, average basal area, and total number of trees by comparing the actual values for each plot with values estimated from the curves for the given age and site index. The sum of the actual values for each factor was divided by the sum of the curve values to obtain an aggregate deviation. For average basal area the individual values were weighted by actual number of trees on each plot. Then the percentage deviation of the individual plots from the curve values were averaged without regard to sign to obtain the average deviation. The following results were obtained:

	Aggregate	Average deviation
Total cubic-foot volume per acre..........per cent..	+3. 24	18. 42
Basal area per acre..........do....	−1. 90	17. 30
Average basal area..........do....	+. 33	19. 01
Total number of trees..........do....	+1. 20	23. 41

From these figures it appears that in general the tables are conservative, since the actual plot values average higher than the curves. The comparatively high figures for average deviation give some measure of the great variation in stand character encountered even among plots selected for uniformity of stocking, but in application these wide variations are taken care of in part by making corrections for differences in stocking.

DETERMINATION OF THE SPRING-BROOD EMERGENCE OF ORIENTAL PEACH MOTHS AND CODLING MOTHS BY VARIOUS METHODS [1]

By ALVAH PETERSON, *Senior Entomologist*, and G. J. HAEUSSLER, *Junior Entomologist, Division of Deciduous Fruit Insects, Bureau of Entomology, United States Department of Agriculture*

INTRODUCTION

During the course of several years' investigations of the life history of the oriental peach moth, at Riverton, N. J., a number of interesting and important facts have been learned. Some of these pertain to the best methods of handling material. In this paper the writers present some of the results obtained from several methods used in determining the spring-brood emergence of the oriental peach moth (*Laspeyresia molesta* Busck) and of the codling moth (*Carpocapsa pomonella* L.). The purpose has been to develop a method which would give results that closely resemble the actual emergence of spring-brood moths in the orchard.

In this preliminary report only the more striking results are discussed. Lack of space prevents a detailed discussion of the relationship existing between the emergence and the weather conditions. The effect of temperature could be shown by graphs of daily temperature and emergence. All of the information relating to spring-brood emergence is shown in the tables and the plotted percentage curves. (Figs. 7, 8, and 9.) These curves show for each method the beginning and the end of the emergence period and also the dates when 2.5, 10, 25, 50, 75, 90, and 97.5 per cent (see arrows on curves) have emerged.

In 1924, when the senior author made his first detailed study on the life history of the oriental peach moth, and also in succeeding years, it was observed that spring-brood moths in an open screened insectary (shaded by a roof) emerge several weeks later than they normally do in an orchard. The normal orchard emergence was determined by means of bait pans and from the presence of fresh empty pupal skins. This information has shown that insectary material alone should not be relied upon for the beginning of a seasonal life-history study.

During the dormant season of 1925–26 some preliminary tests with various boxes and open screen cages containing overwintering oriental peach-moth larvae were made in a peach orchard. The cages and boxes were placed on the ground and 5 to 6 feet above the ground. Some of the cages faced south, others north, and still others faced upward. The differences in the emergence of the moths under the varying conditions were so striking in some instances that it was decided to make a more extensive study of this subject during the winter and spring of 1926–27 with oriental peach moths and codling moths.

[1] Received for publication Apr. 20, 1928; issued November, 1928.

APPARATUS

During the dormant seasons of 1925–26 and 1926–27 several types of screen cages were employed. All types of cages were covered with 16-mesh copper screening, except type *B* which had 24-mesh galvanized screening.

In 1925–26 cages of types *A* and *B* were used. The type *A* cage measures 5 by 6 by 8 inches and is made of wood with 1-inch square wooden supports for the screening. About 75 cocoons may be tacked to the narrow detachable wooden strips (lathing) which are suspended on the inner surface of the solid back board. Type *A* cages were placed on poles or hung on the trunks of peach trees near the ground. (Fig. 1, A.)

The type *B* cage is similar to the type *A* cage but larger. (Fig. 1, B.) It measures 6 by 12 by 15 inches and contains four detachable wooden blocks (1 by 2.5 by 13 inches) on which approximately 300

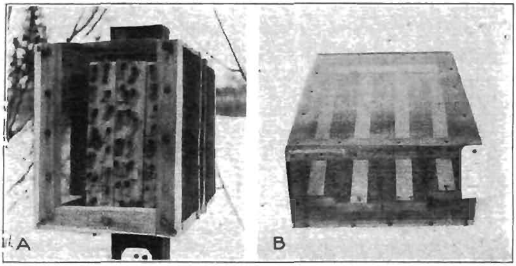

FIG. 1.—Screen cages used in spring-brood emergence studies of the oriental peach moth and the codling moth, Riverton, N. J., season of 1925–26; A, type *A* cage; B, type *B* cage

cocoons may be placed. The solid wooden side of the cage is placed at the bottom, and the blocks rest on the inner and upper surface in such a manner that one end of each block is elevated slightly so rain will drain off readily. The cages were placed on the ground or on a rack 5 feet above ground and the cocoons in all cases faced upward.

During the dormant season of 1926–27 cages of types *C* and *D* were employed. These cages are larger than those of type *A* and differ from both types *A* and *B* in that they have no wooden supports for the screening, consequently all shadows are eliminated except that thrown by the wire. The type *C* cage is 4 by 10 by 14 inches and opens like a book. (Fig. 2, A; fig. 3.) Cages of this type were used chiefly on poles with oriental peach-moth larvae. The type *D* cage is 6 by 9 by 13 inches, and the cocoons are placed on detachable blocks of wood (1 by 2.5 by 8 inches) which rest against the back of the cage. (Fig. 2, B.) These blocks may be removed through a 4 by 6 inch opening in the solid lower side. The opening is closed with a sliding metal plate. Cages of this type were used chiefly in 1927 for codling-moth larvae; they were used also in the moisture experiments in the insectary.

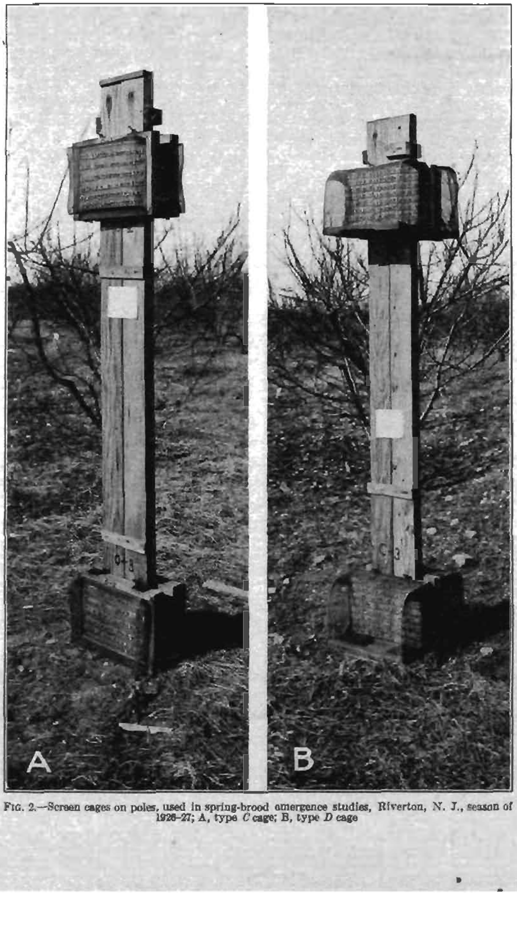

FIG. 2.—Screen cages on poles, used in spring-brood emergence studies, Riverton, N. J., season of 1926–27; A, type *C* cage; B, type *D* cage

The type *C* cage which opens like a book proved to be the most satisfactory to handle. An occasional adult may escape upon opening a cage of this type, but it is easily recaptured if the cage is opened before a window or on the light side of a screened insectary.

Type *E* cages (fig. 4, A) made of wire strainers of various sizes were also found useful when a small number of cocoons were under observation. These are easy to make and may be placed almost anywhere in an orchard. They were not used in any of the tests reported in this paper.

The covered wooden box (fig. 4, B; fig. 5, *a*) measures 6 by 13 by 16 inches, has a 16-mesh copper-screen bottom, round screen-covered holes on the sides, and a detachable lid covered with roofing paper. Two-dram homeopathic vials plugged with cotton, each containing one overwintering larva in a cocoon spun in a piece of corrugated paper, are placed within the box in an upright position in portable wooden frames. The capacity of the box approximates 300 vials. This box is very similar in structure to those used by T. J. Headlee in his codling-moth investigations, and the writers are indebted to him for the idea.

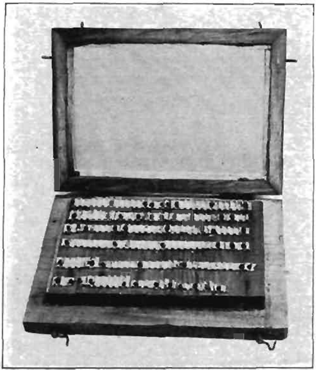

FIG. 3.—Type *C* screen cage, open

A heavy canvas band, about 5½ feet long, was so constructed that it held two parallel rows of 2-dram shell vials placed in small pockets. (Fig. 6.) There were approximately 220 vials in the two rows. These were plugged with cotton and placed in the pockets upside down so that water would not collect in them. The band was placed around the trunk of a large apple tree, approximately 2 feet above the ground. The past season (1926–27) overwintering larvae of the oriental peach moth in cocoons were placed in the canvas band. This canvas band resembles the canvas band used by W. A. Ross of Vineland, Ontario, to whom the writers are indebted for the idea.

The insectary, where a considerable quantity of overwintering material was kept, is an open room screened on three sides and covered with a hip roof covered with tarred roofing paper. In most cases the individual cocoons spun up in corrugated paper were placed in separate 2-dram vials which were plugged with cotton. The vials stood upright in wooden frames, which in turn were placed in wooden trays and kept in the center of the room about 4 feet above the ground. No direct sunlight reached the vials.

The packing house (or storage barn) used in the experiments was a medium-sized building (25 by 40 feet) located near Riverton, N. J.,

adjacent to a cherry orchard. The building had no windows, but had a large sliding door on the north side which was closed most of the time. The overwintering larvae spun up in corrugated paper were placed in a screen cage (11 by 21 by 21 inches), which was placed on the floor of the building, about 3 feet above ground, among the baskets (old and new) which were stored in the building.

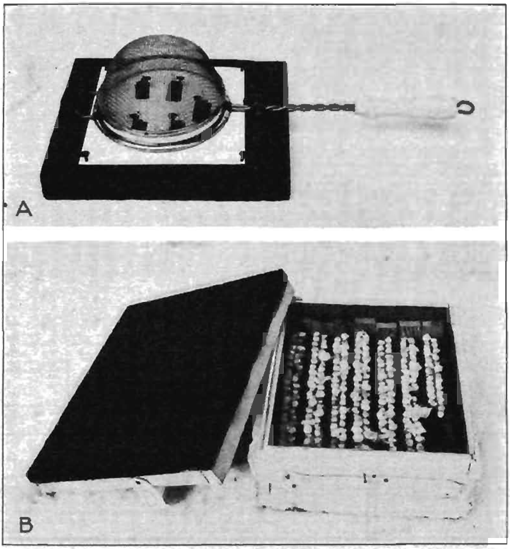

FIG. 4.—A, Type *E* screen cage, useful for a small number of cocoons; B, covered wooden box used in spring-brood emergence studies, Riverton, N. J.

METHODS

Most of the overwintering larvae, in cocoons, of the oriental peach moth and the codling moth used in the tests reported upon in this paper were spun up in corrugated straw paper. In a few instances the larvae in some of the boxes and a portion of the larvae in the canvas band spun their cocoons against the glass in shell vials. All pupation records were made by observing larvae that had spun their cocoons against the glass of 2-dram vials stoppered with cloth-covered cotton plugs.

Daily examinations were made from April 1 to midsummer of all material in the screen cages, boxes, canvas band, insectary, packing

house, and elsewhere for adult emergence. Usually the moths of both species emerge during the morning hours. On warm days moths start to emerge at sunrise or shortly thereafter, whereas in cool weather emergence may not start until 9 o'clock or later and may continue until the early part of the afternoon. Counts and sex determinations were made each day late in the afternoon, including Sundays and holidays.

All overwintering cocoons of oriental peach moths were placed in their respective positions late in the fall or during midwinter, never any later than January. General observations and also two experiments show that the date of transferring the reared or collected overwintering larvae from the insectary to the outdoor cages or other

FIG. 5.—Wooden rack 5 feet high, supporting covered wooden boxes (*a*) and a type *B* screen cage (*b*). (Insectary in background)

containers has little or no influence on the emergence of the moths, provided the larvae are not kept in the insectary much after February 1. The date of placing material in the field seems to have a slight influence on mortality. Material placed outdoors in November or earlier may show a slightly greater mortality than similar material placed in the orchard during January.

All overwintering larvae of the codling moth used in the tests were collected from cloth bands in apple orchards during October and November. Whenever larvae were removed from their original cocoons on the trees they were placed in glass containers filled with corrugated paper strips and permitted to remain in a fairly warm room (temperature at least 50° F.) for 24 to 48 hours so they might spin new cocoons. This act of respinning cocoons probably has some influence on the mortality of codling-moth larvae.

TEMPERATURE

In conducting the studies reported in this paper, temperature records were kept for the several locations where overwintering

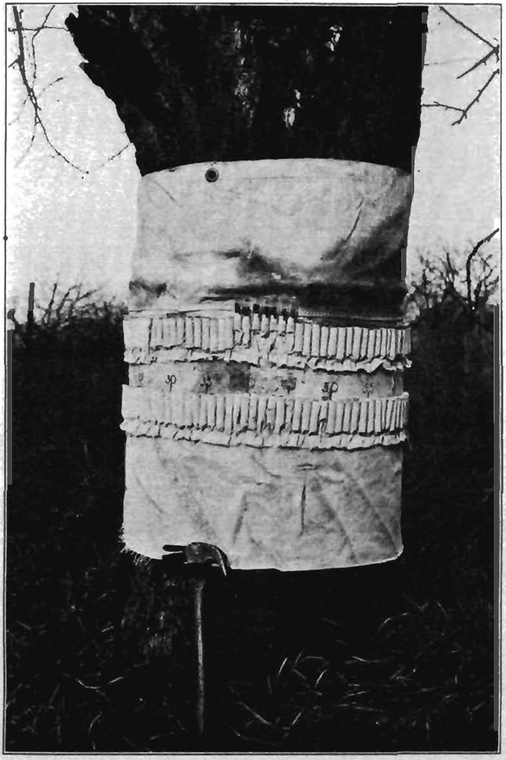

FIG. 6.—Canvas band, with flaps open, used in spring-brood emergence studies of the oriental peach moth, Riverton, N. J., season of 1926–27

larvae were placed, particularly during the season of 1926–27. A mass of data has been assembled on this subject; at this time, however, no attempt will be made to correlate these temperature data

in detail with the facts reported herein. The writers present this paper at this time in order to obtain constructive criticism which will be of assistance in future studies on temperature and other factors. Some of the more important facts learned to date from the temperature records will be discussed briefly.

The data show that there may be very great differences in temperature in the various situations in or about a fruit tree at any given time. This is particularly true on clear days when the sun shines brightly. In other words, the temperatures recorded on a thermograph placed in the shade in an orchard are not the actual temperatures to which many overwintering larvae are subjected, especially on clear days.

The decided differences in temperature that may occur on the north and south exposures of a fruit tree on clear days in the spring of the year (based on records in March, 1927) are shown in Table 1. It will be noted that the four spirit thermometers used in recording the temperatures were placed in four locations similar to those of the cages placed on the north and south sides of a pole. Midday readings on a clear day show temperatures on the south side that may be 15° to 20° or more above those on the north side, whereas on cloudy days all of the readings of the four thermometers may be the same. Also the temperatures near the ground are usually a few degrees higher than the temperatures 5 feet above ground with the same exposure.

TABLE 1.—*Comparison of temperature records from four spirit thermometers placed on the north and south sides of poles in locations similar to those of the cages, the thermometers facing north being shaded*

Date and conditions	Exposure	Height of bulb from ground	Temperatures at—									
			8 a. m.	9 a. m.	10 a. m.	11 a. m.	12 noon	1 p. m.	2 p. m.	3 p. m.	4 p. m.	5 p. m.
			°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Mar. 10, 1927: Clear day; gentle wind	South	5 ft.	48.0	47.0	56.0	59.0	66.0	70.0	68.0	69.0	69.5	61.0
	North	5 ft.	37.0	38.0	44.0	46.0	50.0	53.0	54.5	55.0	54.5	52.0
	South	2 in.	48.0	48.0	58.0	64.0	70.0	74.0	75.5	74.0	69.0	59.0
	North	2 in.	38.0	39.5	46.0	50.0	53.0	56.0	58.0	57.0	56.5	53.0
Mar. 14, 1927: Cloudy day; gentle wind	South	5 ft.	60.0	60.0	63.0	62.0	58.0	57.0	57.5	57.0	56.5	57.0
	North	5 ft.	59.0	60.0	63.0	62.0	61.0	55.0	57.0	57.5	58.0	57.0
	South	2 in.	61.0	60.0	64.0	62.0	59.0	57.5	59.0	59.5	56.0	58.0
	North	2 in.	60.0	60.0	64.0	63.0	60.0	57.0	58.0	58.0	58.0	55.0

The information in Table 1 shows clearly that emergence data taken from a given lot of overwintering larvae placed in a box or some other container located in some one spot in an orchard, with all parts of the container subjected to the same temperature, will not coincide with the normal spring-brood emergence in the orchard. In choosing a method to determine spring-brood emergence, an investigator should take into consideration the decided temperature variations in sunlight and in shade to which overwintering larvae in an orchard are subjected. The two methods discussed in this paper, in which consideration is given to the effect of sunlight and shade on temperature, include the use of the open screen cages and the canvas band.

MOISTURE

Moisture seems to have some influence on the mortality and the development of spring-brood oriental peach moths and codling moths. Overwintering cocoons spun up in corrugated paper and kept dry under insectary conditions show a much greater mortality than cocoons soaked in water occasionally. (Table 3, M, N; Table 4, L, M.) During the 1926–27 season two cages (type *D*) of overwintering oriental peach-moth larvae and two cages of codling-moth material, each containing 300 or more larvae, were assembled in the fall and kept in an open screened insectary. From January 4 to July 5 the blocks of wood containing the cocoons of one cage of each species were removed once a week and submerged in water (at the temperature of the air) for two hours (the total time soaked being 54 hours) and then replaced in the respective cages. At each soaking the corrugated paper became thoroughly wet. In fact, in warm weather the soaking was so thorough that in a few instances it caused some of the larvae to abandon their cocoons.

These results showed that the wetted oriental peach-moth larvae produced adults a few days earlier than those which had never been in contact with water, while with the codling moth material the reverse was true in that the soaking delayed the emergence somewhat. This observation on the reaction of overwintering larvae of the codling moth to moisture does not agree with the results obtained and conclusions drawn by Townsend.[2] He soaked codling-moth cocoons several times at the rate of two hours per week, and the moths emerged sooner than from the dry material. The above wet and dry tests were repeated in 1927–28 with 1,000 or more individuals of each species. The emergence dates, particularly the peaks of emergence, for the wetted and dry material, coincided for each species. This corroborates the results obtained in previous tests and tends to support the conclusion that moisture has little or no influence on the time of emergence of the spring-brood moths.

MORTALITY OF LARVAE

The mortality (Tables 2, 3, and 4) of overwintering larvae of the oriental peach moth in all of the tests made was lower than that of the codling moth under similar conditions, except in one test (Table 3, N; Table 4, L). Although this may be a general and normal condition, the following facts probably had something to do with the results: All of the oriental peach-moth larvae used in the tests were reared in the insectary and therefore each larva spun but one cocoon. There was one exception to this; two cages (Table 2, F, G) contained field-collected larvae that spun their cocoons in corrugated paper, and the mortality in these open screen cages of type *B* was high (26 to 32 per cent) compared with the average (5.6 per cent) for reared larvae in open cages of type *C*. (Table 3, I.) As previously mentioned, all of the overwintering codling-moth larvae were collected from under burlap bands in October and November and respun their cocoons in corrugated paper. This respinning probably accounts for some of the mortality.

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[2] TOWNSEND, M. T. THE BREAKING-UP OF HIBERNATION IN THE CODLING MOTH LARVA. Ann. Ent. Soc. Amer. 19: 429–439. 1926.

The mortality of the overwintering material of both species in the cages of types *C* and *D* on the poles showed the lowest average (oriental peach moths 5.6 per cent and codling moths 15.2 per cent) for all of the methods used. (Table 3, I; Table 4, I.) The mortality of the material in the covered boxes (20 to 41 per cent) and also of the larvae in cocoons which were kept dry (28 to 45 per cent) in the insectary (not in vials) was high. Under insectary conditions the overwintering oriental peach-moth larvae in vials showed a comparatively low mortality (8 to 9 per cent).

The authors are of the opinion that an environment which shows the lowest mortality record is more likely to resemble a natural situation than an environment which produces a high mortality.

EMERGENCE OF MOTHS

EMERGENCE IN SCREEN CAGES

Field observations of the emergence of the spring brood of oriental peach moths have shown that overwintering larvae located on the south side of the trunks of fruit trees emerge much sooner than those located on the north side. It is evident that the direct rays of sun light striking the cocoons located on the south side raise the temperature considerably, and as a result the larvae on the south side undergo their changes or transformations much earlier than larvae under shaded conditions. With this information in mind the authors constructed open screen cages so the cocoons within could be fully exposed to sunlight.

Preliminary tests were made in the dormant season of 1925–26. Eight screen cages of type *A* (fig. 1, A) were placed on two poles in the midst of peach trees in a small peach orchard. Four of the cages faced north and four faced south. Two of the north cages and two of the south cages were next to the ground and two of the north cages and two of the south cages were 5 feet above the ground. Pole No. 1 was situated in an open space between the trees, and pole No. 2 was on the north side and adjacent to the trunk of a 4-year-old peach tree which had not been pruned for two years. The results obtained from the respective cages on the two poles were nearly alike, consequently they were combined, and the results are shown in Table 2, A–G, and Figure 7, A–G. However, the two south cages adjacent to the ground showed a small difference in that emergence in the south ground cage located on pole No. 2 was two days later than in the south ground cage located on pole No. 1. This difference was undoubtedly due to the fact that the trunk and larger branches of the tree south of pole No. 2 cast a shadow on the cocoons in the south ground cage.

The differences in the emergence from cocoons in type *A* cages on the south and north sides of a pole or tree and also adjacent to the ground and 5 feet above are shown in Figure 7, A–D. The cocoons on the south exposure produced adults much earlier than cocoons located in the shade. It was also noted that the cocoons near the ground produced adults 24 to 48 hours sooner than those 5 feet above ground on the same side of the pole or tree. These results agree in general with the differences in temperature noted in Table 1 for the four locations.

TABLE 2.—*Spring-brood emergence of oriental peach moths from overwintering larvae, kept under different conditions, Riverton, N. J., 1926*

	Container	Location and conditions	Number of cocoons	Number of moths	Larvae dead	Date of first emergence	Date of 50 per cent emergence	Time (days) required for emergence of— 10 per cent	25 per cent	50 per cent	75 per cent	90 per cent	100 per cent
					Per cent								
A	Cage type *A*.	Pole, south, ground	[a]290±	273	[b]5.8	May 3	May 7	1	2	4	6	9	28
B	do	Pole, south, high	[a]140±	134	[b]4.2	do	May 8	2	3	5	7	9	24
C	do	Pole, north, ground	[a]255±	240	[b]5.8	May 9	May 17	3	4	8	15	20	34
D	do	Pole, north, high	[a]130±	124	[b]4.6	May 10	May 18	3	5	8	13	20	42
E	do	Four cages (A–D) combined.	[a]815±	771	[b]5.3	May 3	May 12	2	4	9	15	22	49
F	Cage type *B*.	Rack, facing up, high.	247	167	32.3	May 2	May 6	2	3	4	6	8	23
G	do	Ground, facing up, under tree.	230	169	26.5	May 4	May 9	2	3	5	7	9	25
H	Covered box.	Rack, vials, high	247	197	20.2	May 12	May 26	5	9	14	20	23	39
I	do	Ground, vials, under tree.	241	140	41.9	May 15	June 3	7	14	19	25	30	47
J	•	Insectary, vials, shaded.	1,087	981	9.7	May 14	do	12	16	20	27	31	55

[a] Number of cocoons approximated. [b] Based on approximate number of cocoons.

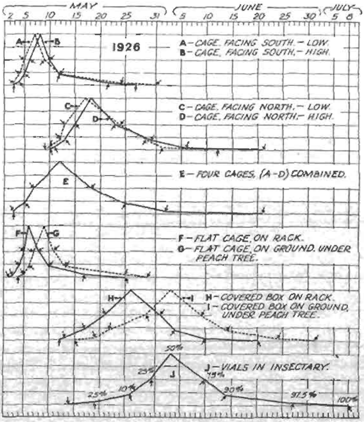

FIG. 7.—Emergence of the spring brood of the oriental peach moth, Riverton, N. J., 1926

In 1925–26 two lots of field-collected oriental peach-moth larvae were placed in two screen cages of type *B*. (Table 2, F, G; fig. 7, F, G.) One cage was located on a rack 5 feet high (fig. 5) and another

was placed on the ground on the north side of a 4-year-old unpruned peach tree. The emergence in these cages was similar to that in the south cages on the poles. The chief difference was that the emergence in the cage on the ground was 48 hours later than in the cage on the rack. This seeming discrepancy may be attributed to

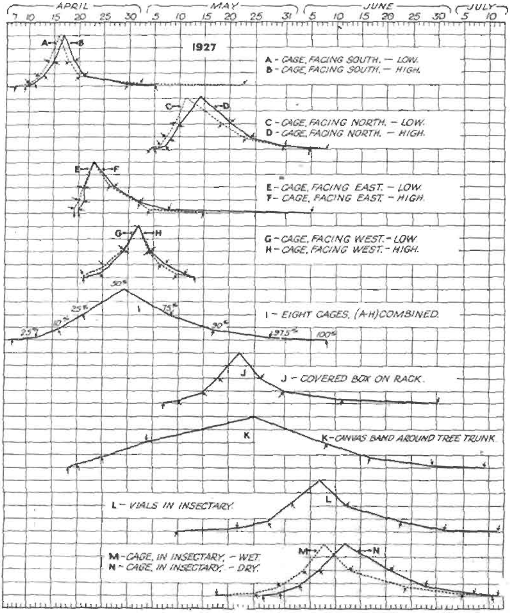

FIG. 8.—Emergence of the spring brood of the oriental peach moth, Riverton, N. J., 1927

the shadows cast by the branches of the peach tree on the cocoons in the ground cage.

More interesting and striking results with screen cages are shown for the dormant season of 1926–27. Eight screen cages of type *C* (fig. 2, A), each containing 300 to 400 cocoons, were placed on two poles in an open space in a small peach orchard. On pole No. 1 two cages faced south and two faced north, and on pole No. 2 two cages faced east and two faced west. On each pole two of the cages (one on each side) were next to the ground and two were 5 feet above the ground. Table 3, A–I, and Figure 8, A–I, show the results obtained in the respective cages.

TABLE 3.—*Spring-brood emergence of oriental peach moths from overwintering larvae kept under different conditions, Riverton, N. J., 1927*

	Container	Location and conditions	Number of cocoons	Number of moths	Larvae dead	Date of first emergence	Date of 50 per cent emergence	Time (days) required for emergence of— 10 per cent	25 per cent	50 per cent	75 per cent	90 per cent	100 per cent
					Per cent								
A	Cage type *C*	Pole, south, ground	331	301	9.0	Apr. 7	Apr. 16	5	7	9	11	13	46
B	do	Pole, south, high	314	287	8.5	Apr. 9	Apr. 17	4	6	8	10	12	26
C	do	Pole, north, ground	417	397	4.7	May 4	May 11	3	5	7	14	19	35
D	do	Pole, north, high	345	323	6.3	May 5	May 14	3	5	9	15	19	31
E	do	Pole, east, ground	353	345	2.2	Apr. 19	Apr. 23	1	2	4	7	13	25
F	do	Pole, east, high	331	320	3.3	Apr. 20	do	1	1	3	7	12	46
G	do	Pole, west, ground	271	248	8.4	Apr. 21	May 2	4	8	11	13	15	22
H	do	Pole, west, high	297	288	3.0	do	do	5	8	11	13	16	22
I	do	Eight cages (A–H) combined.	2,659	2,509	5.6	Apr. 7	Apr. 29	9	14	22	31	40	62
J	Covered box	Rack, vials, high	252	200	20.6	May 7	May 22	8	11	15	19	24	54
K	Canvas band	Vials about tree trunk.	326	285	12.5	Apr. 18	May 25	7	16	37	51	60	82
L		Insectary, vials, shaded.	1,698	1,559	8.1	May 10	June 7	18	22	28	33	44	63
M	Cage type *D*	Insectary, wet	304	255	16.1	May 18	June 8	12	17	21	26	37	55
N	do	Insectary, dry	342	186	45.6	May 27	June 12	7	11	16	25	32	45

The earliest emergence occurred in the south cages adjacent to the ground and the latest emergence occurred in the north cages 5 feet above the ground. There is a difference of 26 to 28 days in the peaks of emergence of the material in the south and north cages. This difference is considerably greater than in 1925–26 and may be attributed to the earlier spring and to the more open cages of type *C*, which did not have any wooden supports that threw shadows on the cocoons, as in type *A* or *B*. The emergence of the material in the east and west cages came between the periods of emergence in the north and south cages. There was a greater difference in the time of emergence in the east and west cages than expected. This may have been due to the fact that the cages (accidentally) did not face exactly east and west for a portion of the time (up to February 15) that they were in the field. The authors are also of the opinion that the apparent difference in the emergence dates was due in some measure to the fact that on numerous days in the spring before emergence started the sun shone brightly during the morning hours but was clouded in the afternoon. The cocoons in the east cages were therefore subjected to more hours of direct sunlight than those in the west cages, and consequently the accumulated temperature was greater. Tests similar to the above were repeated with codling moths and oriental peach moths in 1927–28 with the cages (type *C*) facing exactly east and west during the entire dormant period. The dates of emergence, particularly the peak of emergence, coincided exactly for the two species in the respective east and west cages.

The emergence results from the eight cages combined are shown in Figure 8, I. The authors are of the opinion that this curve closely resembles the curve of actual emergence of oriental peach moths in an orchard. This is probably true if one assumes that overwintering larvae are more or less equally distributed on all sides of tree trunks and branches and on the ground. If such is

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the case, it is probable that the total number of hours of direct sunlight received by the cocoons in the cages approximates the number of hours of direct sunlight received by overwintering larvae in the orchard. There is little or no published evidence to support or contradict this assumption.

In checking the emergence in the cages with the normal emergence in a peach orchard it was observed for three years that the appearance of the first adults or fresh pupal skins in the orchard on the south side of peach trees occurred on the same day or within 24 hours of the time when the first adults emerged in the open screen cages facing south and adjacent to the ground. Furthermore, the period of time when the greatest number of adults were captured in the bait pans coincides very closely with the peak of moth emergence in the eight cages. Bait pans are fairly satisfactory for determining the peak of emergence in an orchard, but they will not indicate accurately the date of the first emergence. Adults may be present in an orchard for 7 to 10 days before they come to baits. This is particularly true of oriental peach moths when an early spring emergence takes place.

The results obtained with overwintering codling-moth larvae in screen cages on poles are very similar to those obtained with oriental peach moths, except for the fact that the time of emergence is later, since it requires more degrees of effective temperature to make a codling moth emerge than an oriental peach moth. For both species of moths the position and nature of the curves which show the emergence in the various containers employed are similar. One of the differences noted is that there is a shorter period of time between the emergence in the south and north cages with the codling moth than with the oriental peach moth. This is probably due to the fact that the daily temperatures average much higher when codling moths are emerging than when oriental peach moths come out. The data relating to the emergence of the codling moth in screen cages, as presented in Figure 9, A–I, and in Table 4, A–I, are self explanatory and consequently will not be discussed.

TABLE 4.—*Spring-brood emergence of codling moths from overwintering larvae kept under different conditions, Riverton, N. J., 1927*

	Container	Location and conditions	Number of cocoons	Number of moths	Larvae dead	Date of first emergence	Date of 50 per cent emergence	Time (days) required for emergence of— 10 per cent	25 per cent	50 per cent	75 per cent	90 per cent	100 per cent
					Per cent								
A	Cage type *D*	Pole, south, ground	299	234	21.7	May 7	May 18	4	7	11	14	17	42
B	do	Pole, south, high	342	282	17.5	do	May 20	5	9	13	16	23	37
C	do	Pole, north, ground	281	239	14.9	May 21	May 30	3	6	9	16	22	39
D	do	Pole, north, high	321	261	18.6	May 23	June 2	3	6	10	15	19	32
E	do	Pole, east, ground	303	283	6.6	May 10	May 19	3	6	9	12	18	38
F	do	Pole, east, high	310	265	14.5	May 13	May 22	4	7	9	14	20	36
G	do	Pole, west, ground	278	233	16.1	May 11	do	5	7	11	16	22	30
H	do	Pole, west, high	342	301	11.9	do	May 23	6	9	12	18	26	41
I	do	8 cages (A–H) combined.	2,476	2,098	15.2	May 7	do	7	11	16	23	31	53
J	Covered box	Rack, vials, high	519	385	25.8	May 10	June 7	10	13	19	22	25	36
K	Screen cage	Packing house	1,300	1,004	22.7	June 6	June 17	5	7	11	16	19	38
L	Cage type *D*	Insectary, dry	325	234	26.0	May 28	June 10	6	10	13	15	25	48
M	do	Insectary, wet	315	259	17.7	May 29	June 12	5	10	14	19	23	48

EMERGENCE IN CANVAS BAND

A canvas band containing rows of vials filled with overwintering cocoons and placed about the trunk of a large fruit tree (fig. 6) is probably the next best method for determining the normal emergence of spring-brood oriental peach moths in an orchard. In a canvas band the larvae are evenly distributed about a tree trunk at a specified height. The vials are shaded by the canvas, yet the cocoons located on the sunny side of the tree are warmed by the direct rays of sunlight, consequently the moths emerge first on the south side and last on the north side.

If a comparison is made between the emergence in a canvas band (fig. 8, K, and Table 3, K) and in the eight open screen cages (fig. 8,

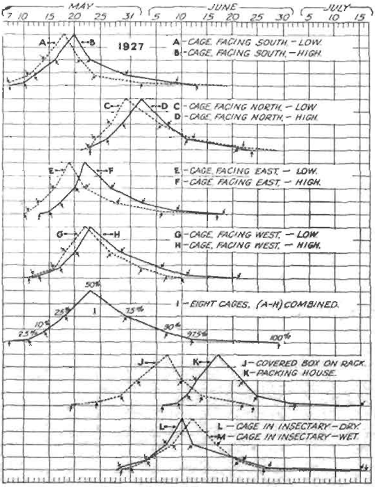

FIG. 9.—Emergence of the spring brood of the codling moth, Riverton, N. J., 1927

I, and Table 3, I), it will be noted that the first moths appeared in the canvas band 11 days later than the first moths in the screen cages and the peak of emergence in the canvas band was 26 days later. Also the period of time required for all of the moths to emerge in the canvas band was 20 days longer than in the screen cages.

The authors are of the opinion that the following are objectionable points in the use of a canvas band for determining the normal emergence of adults in an orchard: In the first place, each cocoon is

in a glass vial, which is by no means a normal condition. The vials collect and hold moisture and during the winter they may be filled with ice crystals. The canvas is apt to retain moisture for a longer time than would be normal on the tree trunk in dry weather. The thick cloth, the vial, and the corrugated paper provide a greater degree of protection and shade over the cocoons than that which normally occurs in most instances in the orchard. A single band at a given height on a tree trunk is a more restricted environment than is found in nature, where many larvae overwinter in cocoons on or near the ground or high up in the trees. The mortality of overwintering material in a canvas band is higher than in open screen cages; this indicates abnormal conditions.

No test was made with overwintering codling moths in a canvas band.

EMERGENCE IN COVERED BOXES

Covered wooden boxes (fig. 4, B) were used for two dormant seasons, 1925–26 and 1926–27. The data relating to emergence of oriental peach moths in these boxes are given for 1926 in Table 2, H, I, and Figure 7, H, I, and for 1927 in Table 3, J, and Figure 8, J. In the spring of 1926 the first oriental peach moths in the boxes emerged 9 to 12 days later than from similar material placed in screen cages (type *A*), whereas in 1927 there was a difference of 30 days in the dates of first emergence in the boxes and in the screen cages (type *C*). Also in 1926 the peaks of emergence of oriental peach moth material in the boxes were 14 to 22 days later than the peak of emergence of the combined south and north cages on the poles. Again, in 1927 the peak of emergence in the box material was 23 days later than in the eight screen cages (type *C*).

In 1925–26 the two boxes occupied different positions. One was on a wooden rack 5 feet above ground and exposed to the direct rays of sunlight, while the other was on the ground on the north side and adjacent to a 5-year-old peach tree which had not been pruned for two years. The material in the box on the rack emerged a few days earlier than the material in the box on the ground which was shaded by the tree. If the box on the ground had not been partially shaded it is probable that the moths would have emerged as soon as or earlier than the moths in the box on the rack. The temperature records show clearly that the ground temperatures are higher during midday than the temperatures 5 feet above ground, particularly on clear days, and the open screen cages show that material on the ground emerges sooner than up in the air if all other conditions are the same. If the boxes had been placed in a tree and partially shaded by the branches the emergence would undoubtedly have been as late as and probably later than that from the boxes placed on a rack and fully exposed to the sun all day.

A delay of two to three weeks in the emergence of oriental peach moths from overwintering larvae kept in a covered box has occurred for three seasons. The peak of emergence from the box material the past season (1926–27) was even later than the peak of emergence from cocoons facing north in the cages.

Overwintering codling-moth larvae were placed in covered boxes for two seasons. The results obtained for one season, 1926–27, are shown in Table 4, J, and Figure 9, J. In this test the first codling moths in

the box emerged 12 days later than the first moth in the orchard or in the south cage near the ground. The peak of emergence in the box is also 15 days later than that in the eight open screen cages (fig. 9, I, and Table 4, I), which has been shown to resemble closely the normal emergence in an orchard.

In some respects the emergence from overwintering larvae kept in a box is comparable with the emergence occurring in a canvas band. Some of the objections raised concerning the use of a canvas band also apply to a covered box. In a covered box the overwintering larvae in corrugated paper are kept in glass vials plugged with cotton. The box serves as a partial insulation against rapid changes in temperature which occur in the spring of the year on clear days. It has been repeatedly noted that the temperature during midday within the boxes may be considerably lower than the outside air temperature. The mortality of overwintering oriental peach-moth larvae in covered boxes (20 to 41 per cent) is much higher than the average mortality (5.6 per cent) in the open screen cages. The foregoing facts indicate that overwintering larvae placed in a covered box behave differently from larvae in a more natural environment.

EMERGENCE IN INSECTARY

For several dormant seasons overwintering oriental peach-moth larvae have been kept in a screened insectary. Each year the beginning date and the peak-of-emergence date have been several weeks later than the normal emergence in the orchard or in the open screen cages. The greatest difference occurred the past season, 1926–27. The first emergence in the insectary, May 10, occurred 33 days after the first emergence in the orchard or in the screen cages, April 7, and the peak of emergence in the insectary, June 8, was 40 days later than the peak of emergence, April 29, in the eight cages on the poles. Also the emergence period in the insectary was approximately as long as the emergence period in the eight screen cages. Data for 1926 are shown in Figure 7, J, and Table 2, J, and for 1927 in Figure 8, L–N, and Table 3, L–N.

Codling-moth larvae kept in an insectary also emerge two to three weeks later than the normal emergence in an orchard. (Table 4, L, M, and fig. 9, L, M.)

The striking differences in the dates of emergence of insectary material and of normal outdoor larvae are of decided importance if a life-history study under insectary conditions is contemplated or if control recommendations are to be made which are based on spring-brood emergence of moths in an insectary.

EMERGENCE IN PACKING HOUSE

During the season of 1926–27 the writers did not have sufficient oriental peach-moth material to place a goodly number in a grower's packing house. Previous experience has shown that the emergence of oriental peach moths in an open screened insectary closely resembles the emergence that occurs in an open packing house where a grower may store old baskets that contain overwintering larvae.

In 1926–27 overwintering codling-moth larvae were placed in a closed packing house among old and new fruit baskets. From this

material moths emerged much later than from larvae in the orchard. (Table 4, K, and fig. 9, K.) The first adults in the packing house, June 6, appeared 30 days later than the first adults in the orchard, May 7, and the peak of emergence in the packing house, June 17, was 25 days later than the peak of emergence in the open screen cages, May 23.

This decided delay in the emergence of moths in a packing house is important, especially if the packing house is located near a block of fruit trees, where adults which emerge late are likely to interfere with a control program based upon the normal emergence of moths in the orchard.

SUMMARY AND CONCLUSIONS

It has been repeatedly observed in orchards that overwintering larvae of the oriental peach moth and the codling moth located on the southern exposure of tree trunks and usually near the ground are the first individuals to change to pupae and emerge as moths in the spring, while moths that emerge late usually come from cocoons located in the most shaded portions of a tree or orchard.

There is a marked difference in the temperature on the south and north sides of a fruit tree on clear days in the spring, whereas little or no difference occurs on cloudy days. Apparently differences in temperature on a sunny exposure and the air temperatures in the shade are directly proportional to the amount of sunlight present.

The presence or absence of moisture about overwintering larvae seems to have a comparatively small influence on the emergence period of the moths; however, it does influence mortality. Overwintering larvae spun up in cocoons in corrugated paper kept in a dry insectary suffer a much greater mortality than similar material wetted frequently. In the various methods employed to determine emergence, the lowest mortality occurred in material confined in open screen cages located on poles or tree trunks where rain, dew, and snow could reach them.

Of the methods tested by the authors, the most satisfactory for determining the normal emergence of spring-brood moths in an orchard proved to be that involving the use of eight screen cages placed on poles (or tree trunks), so that four of the cages were adjacent to the ground and four were 5 feet above ground, and one cage of each group of four faced north, east, south, and west. This method subjects overwintering larvae to all of the elements, rain, snow, dew, wind, and sunshine. It takes into consideration the differences in temperature near the ground and several feet in the air, and also the decided differences in temperature which occur on sunny and shaded exposures. This method permits an equal distribution of larvae in all possible situations which, so far as known, are similar to those in nature. Since there is no evidence to the contrary, it is assumed that overwintering cocoons of both species are more or less equally distributed on all sides of the large branches and trunks of fruit trees and also to some extent on the ground. If such is the case, it is possible that the total hours of direct sunlight received by cocoons in an orchard would approximate the total hours of direct sunlight received by the cocoons located in the eight open screen cages placed as described above.

For two or three seasons the beginning date and the peak-of-emergence date for both species of moths in the screen cages compare very favorably with similar dates in the orchards.

The moth-emergence dates for the respective species of overwintering larvae kept in a canvas band, in covered boxes, in a screened insectary, and in a closed packing house are later or, in some instances, very much later than the normal emergence dates in an orchard or in the screen cages. The latest emergence for oriental peach moths occurred in the insectary, whereas for codling moths the latest emergence took place in a packing house.

A WILT DISEASE OF ALFALFA CAUSED BY FUSARIUM OXYSPORUM VAR. MEDICAGINIS, N. VAR.[1]

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INTRODUCTION

It is the purpose of this paper to report in detail the results of the investigations of the Fusarium-wilt disease of alfalfa (*Medicago sativa* L.) that recently was described briefly by the author (*21*).[3]

REVIEW OF LITERATURE

As stated in the above-mentioned paper (*21*), several writers have reported a root rot or wilt of alfalfa with which a species of Fusarium has been associated. Cottam (*3*) states that the pathogenicity of a root disease of alfalfa in Utah has been traced to the activity of a Fusarium. He describes this disease as being characterized by brown cankerous depressions at the bases of lateral roots, which are entirely destroyed, and he further states that the pathogene attacks both the parenchymatous tissue and the xylem vessels of the taproot. According to Cottam's observations, the diseased plants serve as centers from which the infection spreads in various directions, often destroying an entire field in a single season. He gives no description of the organism and cites no experiments to prove its pathogenicity. Judging from his description, the disease is evidently not the one under consideration in this paper.

Arnaud (*1*) describes a disease of alfalfa in France that he attributes to *Neocosmospora vasinfecta* (Atk.) Smith. He emphasizes the presence of the brick-red perithecia on the diseased roots, and apparently concludes that they belong to the fungus that causes the disease. He cites no proof that the disease under observation was caused by a Fusarium, although he considers it to be the same disease as that occurring on cotton. He compares the disease to that caused by Rhizoctonia and does not mention any symptoms that would indicate that he was dealing with a wilt.

McCallum (*7*) discusses a root rot attributed to a Fusarium that attacks alfalfa, tomatoes, melons, cantaloupes, and other crop plants, and states (*8*) that the most destructive diseases as a group in Arizona are those due to Fusaria. To this group belong the root rots or wilts of alfalfa. These diseases on alfalfa are said to be very destructive, often ruining a large part of the crop. Affected areas in the field

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[1] Received for publication July 30, 1928; issued November, 1928. Cooperative investigations between the Kansas Agricultural Experiment Station and the Bureau of Plant Industry, U. S. Department of Agriculture. This paper is No. 281 of the Department of Botany and Plant Pathology, Kansas Agricultural Experiment Station.

[2] The writer is indebted to H. L. Westover, senior agronomist, and T. F. Akers, agent, of the U. S. Department of Agriculture, for sending much of the field material studied and for assistance with the experimental and survey work at West Point, Miss.

[3] Reference is made by number (italic) to "Literature cited," p. 432.

usually start as small spots that gradually enlarge in a more or less concentric manner. The first indication of the disease is shown by a yellowing of the outer leaves of the affected plants. This chlorotic condition gradually becomes more pronounced until all the leaves and even the stems have lost their green color. This is either accompanied, or more usually followed, by the wilting and death of these parts. McCallum gives no description of the fungus. From his meager accounts it is impossible to tell whether or not he is describing the disease that the present writer has studied. Judging from his description of the manner in which the disease spreads in the field, it is thought that the two diseases are different.

Brown and Gibson (*2*) give a photograph of an alfalfa plant affected with a crown rot and discuss a root rot caused by *Fusarium* sp. Apparently they did not isolate the fungus and prove that the disease in question was due to the Fusarium associated with the lesions.

Selby (*15*), Selby and Manns (*16*), Piper (*10*), Weniger (*22*), and others discuss a root rot of alfalfa attributed to *Fusarium roseum*.

Tehon (*18, 19*) reports root and crown rot and wilt of alfalfa from Illinois. A personal conference has developed the fact that these diseases differ from the wilt disease described in the present paper.

Robbins and Scott (*12*) report a Fusarium species closely associated with a blighting of alfalfa. Scott (*14*) states that in studies of Fusarium blight of alfalfa additional species of the fungus were isolated, but apparently none that had been previously reported.

Weimer (*20*) recently has described various types of alfalfa root diseases from many of which a species of Fusarium could almost always be isolated. However, the disease could not be reproduced by inoculating these Fusaria into healthy plants. When conditions were made extremely favorable for the fungi, damping off of seedlings could be produced with most of the organisms isolated.

Reports of alfalfa root rots or wilts have been received by the Plant Disease Survey from nearly every State where alfalfa is grown. These reports show that Fusaria are commonly associated with alfalfa-root troubles in many States.

Still further references could be given in which workers have found a species of Fusarium associated with a type of root rot or blight of alfalfa. However, in no case has the writer found a description of a typical Fusarium wilt such as is common in many other crops. The Fusarium wilt in other hosts is so well known that this disease in alfalfa would undoubtedly have been described in a manner that would leave no doubt as to its nature had it been seen by the other workers who have reported root diseases of this plant.

THE DISEASE

DISTRIBUTION AND ECONOMIC IMPORTANCE

The Fusarium wilt of alfalfa was first found in September, 1926, by H. L. Westover at the experiment farm near West Point, Miss., where forage-crop field experiments were conducted in cooperation between the Bureau of Plant Industry and the State Agricultural Experiment Station, and specimens were submitted by him to the writer for diagnosis. Later a survey was made of the alfalfa-growing sections of northeastern and east-central Mississippi and of central Alabama. The disease was found in several fields in northeastern

Mississippi near Aberdeen, Muldon, and West Point, but not in Alabama.

In April, 1926, B. A. Madson sent the writer specimens of diseased alfalfa plants from Chino, Calif. Among these were two plants that exhibited all the symptoms of Fusarium wilt. From these plants a Fusarium that appeared to be identical with that from Mississippi was isolated. Inoculation experiments were made and infection obtained. The Fusarium was reisolated and again used in inoculation experiments with positive results. Later, however, one of the check plants became infected. As this made the earlier results of questionable value, the experiment was repeated, a culture of the fungus from the original isolation being used. This test gave negative results under conditions similar to those in which the Fusarium from Mississippi gave a high percentage of infection. There is therefore some doubt as to the occurrence of this disease in southern California. It is possible that a mixed culture was obtained from the original isolation and that the parasite was overgrown by a saprophyte and eventually lost.

Although the occurrence of the disease has been definitely proved only in Mississippi, it seems probable that it will eventually be found elsewhere. From the present knowledge of the disease no reason can be seen why its distribution should be so limited. The disease appears to be too limited in its distribution to be of very great economic importance at the present time. In fields where it does occur, however, it causes the stand to thin out gradually. From a plot of 1-year-old alfalfa growing on the Government experiment farm at West Point, Miss., plants from areas about a yard square were dug up and the percentage of diseased plants was determined. Three areas were dug to get a representative sample from different parts of the plot. The plants were cut open and examined carefully for vascular browning. Counts made in this manner in April and August, 1927, showed an average of 12.5 and 8.5 per cent, respectively, of infected plants. The fields in which the disease has been seen had from a trace to 15 per cent of affected plants as nearly as could be estimated.

SYMPTOMS

The symptoms of this disease vary. Sometimes the upper leaves turn bright yellow, this color gradually fading to a light buff and finally to the color of dead and bleached alfalfa straw. Again, some of the basal leaves may have a tinge of old rose or some shade of pink. In other cases the tips of the stems droop and wilt during the warm part of the day or when the soil becomes too dry, but they may become turgid again when more water becomes available or transpiration is decreased. Sometimes the leaves die rapidly and become dry and brittle, but they retain much of their green color just as they do when cut for hay. Usually the disease becomes evident first in one stem that may be entirely dead before any signs of infection appear elsewhere. The entire plant dies gradually, sometimes requiring weeks or even months to succumb entirely. Stunting of the plant is sometimes an early symptom, but often this is not noticed until the plant shows evidence of approaching death. The plant at the left in Figure 1 shows an extreme case of dwarfing. Probably the other plants were infected at the time the photograph was taken, as they

showed evidence of a diseased condition soon afterwards, but at that time they were as large as the controls. In Figure 2 the plants

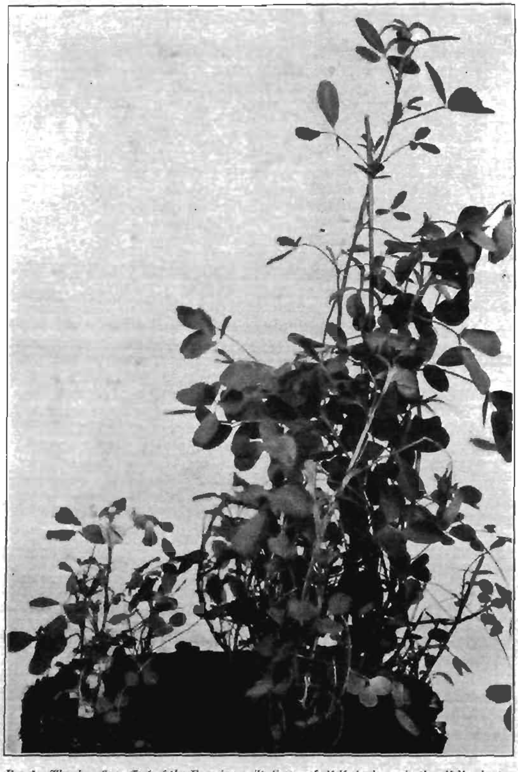


FIG. 1.—The dwarfing effect of the Fusarium-wilt disease of alfalfa is shown in the alfalfa plant at the left, which was inoculated by inserting spores and hyphae beneath the bark of the taproot near the crown. The plants at the right were inoculated also, but infection did not become evident until later. About one-half natural size

at the right show different stages of the disease, and those at the left are uninoculated controls.

The roots of affected plants usually appear normal in the early stages of infection. Sometimes the roots of young diseased alfalfa

plants are darker in color than normal because of the browning of the vascular bundles within, resembling in such cases young sweetpotato (*Ipomoea batatas*) plants affected with the so-called bluestem disease caused by *Fusarium hyperoxysporum* Wollenw. As in

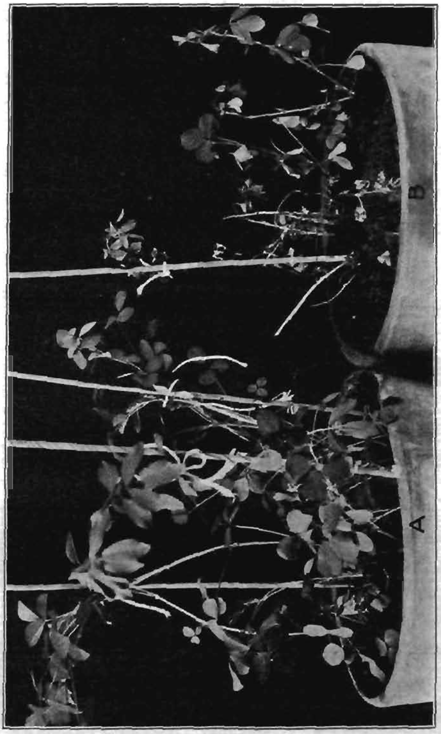


FIG. 2.—The alfalfa plants at the right (B) show various stages of the Fusarium-wilt disease; those at the left (A) were uninoculated controls. About three-eighths natural size

other diseases of this type, the infection becomes evident when the vascular region is exposed by the removal of the outer bark of the root. The color of the invaded vascular system varies considerably, but usually ranges from cinnamon brown to mummy brown as given in Ridgway's (*11*) color standards. The amount of discoloration

varies greatly, depending upon the extent to which the infection has spread. When only one stem or a part of the top is killed, a corresponding part of the vascular system of the root is involved. This is illustrated in the cross section of the root in Figure 3, A, in

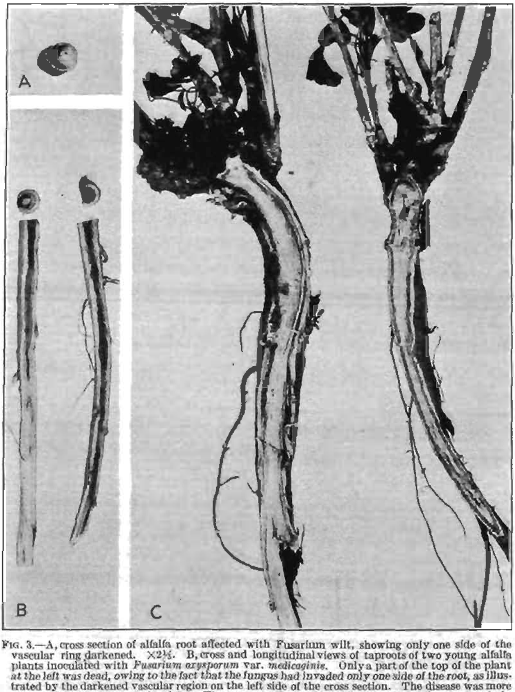


FIG. 3.—A, cross section of alfalfa root affected with Fusarium wilt, showing only one side of the vascular ring darkened. ×2½. B, cross and longitudinal views of taproots of two young alfalfa plants inoculated with *Fusarium oxysporum* var. *medicaginis*. Only a part of the top of the plant *at the left was dead, owing to the fact that the fungus had invaded only one side of the root*, as illustrated by the darkened vascular region on the left side of the cross section. The disease was more advanced in the root at the right. The top was nearly dead; the vascular region was entirely darkened, as shown in the cross section; and the disease had progressed farther downward, as illustrated in the longitudinal view. ×2. C, two alfalfa plants infected in the field at West Point, Miss. The darkened region just beneath the bark shows the area invaded by the fungus. ×2½.

which the vascular ring at the top is discolored. In advanced stages of the disease a large part of the vascular region of both the root and the lower part of the stem may be affected. Figure 3 shows the darkened vascular systems of artificially inoculated (A and B), and naturally infected (C) plants.

Anyone familiar with the Fusarium wilts of other plants should be able to recognize this disease of alfalfa without the slightest difficulty. The only other disease of this plant known to the writer that might be confused with it is the bacterial wilt caused by *Aplanobacter insidiosum* L. McC., recently described by Jones (*5*) and Jones and McCulloch (*6*). One of the most common symptoms of this bacterial disease is a dwarfing of the plant. A very typical example is portrayed in Plate 1, A, of the paper by Jones and McCulloch (*6*). The stems are slender, the leaves are small, and the dwarfed plants are usually paler than their healthy neighbors. No such dwarfing has ever been seen in field plants affected with Fusarium wilt. When the bark of the roots of plants affected with either of these diseases is split open, the vascular regions thus exposed are found to be discolored. This color is yellow or light brown in plants affected with the bacterial wilt and cinnamon to mummy brown in case of the *Fusarium*-wilt disease.

ETIOLOGY

The Fusarium wilt of alfalfa is caused by the fungus *Fusarium oxysporum* var. *medicaginis*, n. var.

SOURCE

As stated previously, the first diseased plants were sent from West Point, Miss., by H. L. Westover. The fungus was readily isolated by planting some of the diseased tissue on acid agar. Single-spore isolations made from the original culture were used for all of the studies herein described. However, isolations made from many other plants obtained at later dates were used in comparative studies. The fungus was isolated from the stems as well as from the roots of diseased plants.

MORPHOLOGY

The morphological characters are as follows: Microconidia abundant, ellipsoidal to cylindrical, 0-septate and 1-septate. Macroconidia gradually attenuate toward both ends, usually nearly cylindrical in the middle half of their length, typically not broader toward the apex, usually somewhat pedicellate; 3-septate, dominant; average 40 by 4.4 μ and range 25 to 50 by 4 to 5.5 μ; in sporodochia and pseudopionnotes; 4-septate macroconidia common; 5-septate frequently seen; 1-septate, 2-septate, and 6-septate rarely present in sporodochia; in mass usually pale ochraceous buff to pale ochraceous salmon; sporodochia small to medium (up to 2 mm. in diameter), often converging into pseudopionnotes; chlamydospores terminal and intercalary, borne singly or in short chains, also commonly present in spores, in mycelium measuring 7 to 11 μ; aerial mycelium typically moderately well developed usually not over 5 mm. high, mostly white. Sclerotia on steamed potato tuber at first light buff to pale flesh, later light blue green becoming bluish black with age. The characteristic spore types are illustrated in Plate 1, A and B.

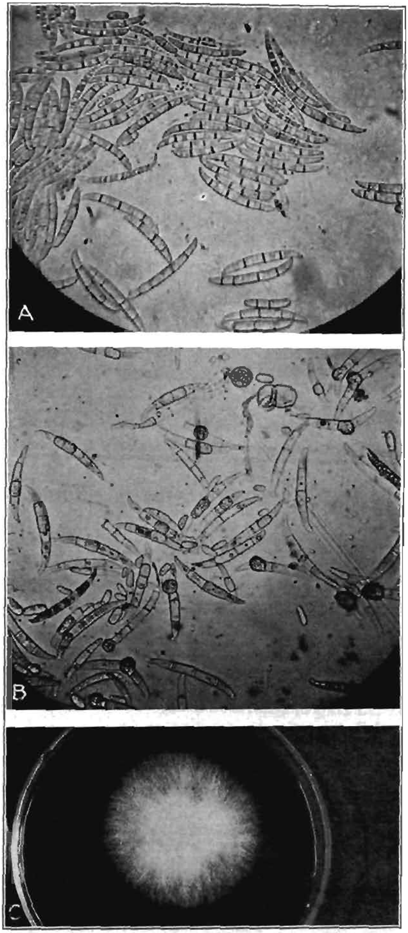
CULTURAL CHARACTERS

In the course of these investigations *Fusarium oxysporum* var. *medicaginis* was grown on several of the culture media commonly used for Fusaria. The medium used most and on which the fungus

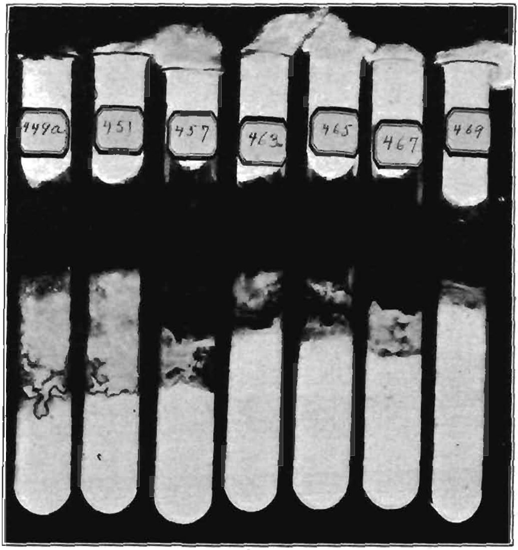
sporulated most vigorously was nutrient agar prepared from the dehydrated bactonutrient agar plus 2 per cent of dextrose. Additional sugar inhibited sporulation and stimulated color production. The typical growth on this medium after four days at 25° C. is illustrated in Plate 1, C. In tube cultures of this medium containing 2 per cent dextrose the mycelium typically was moderately well developed, usually not over 5 mm. high, mostly white except for tinges of light purple when in contact with the medium, and sporodochia and pseudopionnotes were formed in abundance. When 5 per cent or more of dextrose was added a faint orange-pink color developed in the aerial mycelium. The color varied from green-blue slate to slate with occasional tinges of some shade of light purple in the mycelium in contact with the medium. Chlamydospores are formed abundantly in both the spores and the mycelium in cultures on this medium, and sometimes small sclerotia are also formed. Steamed rice in test tubes was probably the most helpful medium in distinguishing this fungus from others that were isolated from time to time from roots with secondary infections. Not only could many secondary Fusaria be eliminated on this medium, but also the alfalfa-wilt Fusarium could be differentiated from other species that were being studied and that were known to cause wilt in other hosts.

The color produced by the alfalfa-wilt Fusarium on rice steamed one hour a day for three days varied from coral pink to Eugenia red to carmine red (*11*). A tinge of color varying from magenta to dull dark purple was present at times where the hyphae came in contact with the tubes. There was usually a small amount of warm-buff color in the rice beneath the hyphae. In a comparative study of this and other Fusarium-wilt fungi the outstanding difference was found to be the rate at which the alfalfa Fusarium penetrated the medium. Comparative tests were made at different times, always using rice tubes prepared in the same manner and handled as nearly as possible in the same way. Cultures of Fusaria from cotton, watermelon, cowpea, tomato, sweet potato, potato, and cabbage were furnished by various workers in the United States. In some cases two or more strains of an organism were obtained from different sources. With the exception of the Fusarium from cabbage, which produced no color, there was nothing strikingly different in the color reactions of these fungi on rice. In practically every case, however, the Fusarium from alfalfa could be separated from the others by the rate at which its mycelium penetrated the rice. The other species formed only a mycelial mat on the surface, while the Fusarium from alfalfa penetrated the medium, forming pockets that were lined with white mycelium. This difference is illustrated in Plate 2, where the two tubes at the left (449a and 451) are the alfalfa Fusarium, while the others are (left to right) from sweet potato, cowpea, watermelon, cotton, and tomato, in the order named. While this character probably will not always hold, it has remained fairly constant in the many tests made in these studies. The alfalfa-wilt Fusarium has more white aerial mycelium and more pink and less purple color in the mycelial mats than is present in those from other hosts. These are only slight physiological differences that may be helpful, but they are not considered to have any specific value.

As *Fusarium oxysporum* var. *medicaginis* formed no sporodochia on potato-tuber plugs, no spore measurements on this medium are given



A, Photomicrograph of macroconidia and microconidia of *Fusarium oxysporum* var. *medicaginis*. The spores were from a pseudopionnotes in a 7-weeks-old culture on nutrient agar. × about 500. B, Photomicrograph of macroconidia, microconidia, and chlamydospores from a 3-months-old culture of *F. oxysporum* var. *medicaginis* on potato agar. × about 500. C, A typical



Rice cultures of six different Fusarium wilt fungi 27 days old isolated from alfalfa (449a and 451), sweet potato (457), cowpea (463), watermelon (465), cotton (467), and tomato (469). These cultures are of the same age and are on the same medium, made by transferring hyphae from Petri-dish cultures also of the same age and on the same medium. Note the greater rapidity with which the alfalfa fungus penetrates the medium and forms pockets lined with white mycelium. The growth of the other fungi was limited largely to the formation of a mat of mycelium on the surface of the medium

below. A white, rather compact mycelial growth formed over the surface of the plugs, with an occasional blue sclerotium, but no other color was produced. On potato agar without sugar the mycelial growth was rather sparse and no color was produced, but thin pseudopionnotes were frequently formed. When 5 per cent dextrose was added a faint orange-pink tint was present in the mycelium in parts of the culture, while scattered about were patches of color varying from green-blue slate to slate. This fungus does not grow very luxuriantly on oat, corn-meal, or Lima-bean hard agars made according to Sherbakoff's directions (*17*). Small sporodochia were formed on most of the cultures, and a small amount of color varying from Rood's violet to raisin purple was present in all except those on Lima-bean agar, where no color was developed. A fairly luxuriant growth of white aerial mycelium and some sporodochia were produced on *Melilotus alba* stems.

The spore measurements were made under the oil-immersion lens. At least 25 and usually more spores (but fewer in case of the 1, 2, 5, and 6 septate spores) from sporodochia or pseudopionnotes, were used for each set of measurements. The dimensions of the spores on the various media are as follows:

On 2 per cent nutrient agar plus 2 per cent dextrose; culture 3 months old:
- Macroconidia—
  - 2-septate.—37 by 4 μ. Rare.
  - 3-septate.—36.2 by 4.58 (25 to 47 by 4 to 5.4) μ. Up to 95 per cent.
  - 4-septate.—44.1 by 4.89 (41.4 to 48.6 by 4.5 to 4.95) μ. Up to 15 per cent.
  - 5-septate.—37.8 by 5.17 (34.2 to 41.4 by 4.95 to 5.4) μ. Only 2 spores measured; up to 1 per cent.
  - 6-septate.—48.6 by 5.4 μ. Only 1 spore measured; rare.
- Microconidia—
  - 0-septate.—7.88 by 3.75 (4.5 to 12.6 by 2.7 to 5.4) μ.
  - 1-septate.—11.34 by 3.91 (9 to 12.6 by 3.6 to 4.5) μ.
- Chlamydospores—
  - In spores.—Intercalary, 8.5 by 7.46 (7.2 to 10.8 by 5.4 to 9) μ.
  - In mycelium.—(a) Intercalary, 9.9 by 9.2 (7.2 to 10.8 by 7.2 to 10.8) μ; and (b) terminal, 11.3 by 11.1 (10.8 to 12.6 by 10.8 to 12.6) μ.

On nutrient agar plus 2 per cent dextrose; culture 7 days old:
- Macroconidia—
  - 3-septate.—38.1 by 4.08 (30.6 to 45 by 3.6 to 4.5) μ.

On nutrient agar plus 2 per cent dextrose; culture 17 days old:
- Macroconidia—
  - 3-septate.—38.4 by 4.16 (34.2 to 41.4 by 3.6 to 4.9) μ.

On 2 per cent potato agar without sugar; culture 60 days old:
- Macroconidia—
  - 1-septate.—34 by 3.6 μ. Rare.
  - 3-septate.—40.1 by 4.52 (34.2 to 49 by 4 to 4.9) μ. Up to 75 to 80 per cent.
  - 4-septate.—43.2 by 4.81 (37.8 to 48.6 by 4 to 4.9) μ. Up to 15 to 20 per cent.
  - 5-septate.—46.8 by 4.9 (41.4 to 54 by 4.9 to 4.9) μ. Less than 1 per cent.
- Chlamydospores—
  - In spores.—Terminal, 6.3 by 5.85 (5.4 to 7.2 by 5.4 to 6.3) μ.

On 2 per cent potato agar without sugar; culture 7 days old:
- Macroconidia—
  - 3-septate.—46.7 by 4.2 (41.4 to 52.2 by 3.6 to 4.5) μ.

On 2 per cent potato agar without sugar; culture 22 days old:
- Macroconidia—
  - 3-septate.—37.6 by 4.53 (27 to 46.8 by 4 to 5) μ.
  - 5-septate.—45 by 4.9 μ. Rare.

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On potato agar without sugar; culture 14 days old:
- Macroconidia—
  - 3-septate.—40.86 by 4.74 (37.8 to 45 by 4.5 to 4.9) μ. Up to 90 to 95 per cent.
  - 4-septate.—45.3 by 4.8 (43.2 to 46.8 by 4.5 to 5) μ. Up to 50 per cent.
  - 5-septate.—48.6 by 5.1 μ. Rare.
- Microconidia—
  - 0-septate.—8.91 by 3.17 (7.2 to 9.9 by 2.7 to 3.1) μ. Up to 95 per cent.
  - 1-septate.—9.9 by 4.05 (9 to 10.8 by 3.6 to 4.5) μ. Up to 5 per cent.

On *Melilotus alba* stems; culture 13 days old:
- Macroconidia—
  - 3-septate.—38.9 by 4.7 (30.6 to 45 by 4 to 5.4) μ. Up to 80 to 90 per cent.
  - 4-septate.—40.2 by 5.2 (37.8 to 43.2 by 4.9 to 5.4) μ. Up to 5 per cent.
  - 5-septate.—48.6 by 5 μ. Only 1 spore measured; rare.
- Microconidia—
  - 0-septate.—10 by 3.64 (7.2 to 12.6 by 3.1 to 4.5) μ.
  - 1-septate.—15 by 3.8 (13.5 to 16.2 by 3.6 to 4.5) μ.

On oat agar; culture 7 days old:
- Macroconidia—
  - 3-septate.—38.9 by 4.7 (30.6 to 45 by 4 to 4.9) μ. Up to 80 to 90 per cent.
  - 4-septate.—48 by 4.8 (41.4 to 52.2 by 4.5 to 4.9) μ. Up to 10 to 20 per cent.
  - 5-septate.—52.2 by 4.9 μ. Rare.

On corn-meal agar; culture 27 days old:
- Macroconidia—
  - 3-septate.—37.8 by 4.59 (23.4 to 45 by 4 to 4.9) μ.
  - 4-septate.—42.1 by 4.8 (39.6 to 46.8 by 4.5 to 4.9) μ.
  - 5-septate.—49.5 by 4.9 (46.8 to 52.2 by 4.9) μ.
  - 6-septate.—54 by 5.4 μ. 1 spore only.
- Chlamydospores, in mycelium—
  - 0-septate.—9.36 by 9.72 (7.2 to 10.8 by 7.2 to 10.8) μ.

On Lima-bean agar; culture 7 days old:
- Macroconidia—
  - 3-septate.—41.9 by 4.65 (30.6 to 48.6 by 4 to 4.9) μ. Up to 80 to 90 per cent.
  - 4-septate.—48.6 by 4.9 μ. Up to 10 to 20 per cent.

On steamed rice; culture 21 days old:
- Macroconidia—
  - 3-septate.—42.9 by 4.4 (37.8 to 46.8 by 4 to 4.9) μ. Up to 95 per cent.
  - 4-septate.—45.5 by 4.34 (39.6 to 48.6 by 4 to 4.9) μ. Up to 5 per cent.
  - 5-septate.—46.8 by 4.7 μ. Rare.
- Microconidia—
  - 0-septate.—8.8 by 3.18 (7.2 to 10.8 by 2.7 to 3.6) μ. Up to 95 per cent.
  - 1-septate.—9.9 by 3.6 μ. Up to 5 per cent.

Average of the above-listed measurements:
- Macroconidia—
  - 1-septate.—34 by 3.6 μ.
  - 2-septate.—37 by 4.0 μ.
  - 3-septate.—40 by 4.4 μ.
  - 4-septate.—44.5 by 4.84 μ.
  - 5-septate.—46.8 by 4.92 μ.
  - 6-septate.—51.3 by 5.4 μ.
- Microconidia—
  - 0-septate.—8.95 by 3.43 μ.
  - 1-septate.—11.9 by 3.89 μ.
- Chlamydospores—
  - In spores.—(a) Intercalary, 8.5 by 7.46 μ; and (b) terminal, 6.25 by 5.4 μ.
  - In mycelium.—(a) Intercalary, 9.72 by 9.36 μ; and (b) terminal, 11.3 by 11.1 μ.

The cultural and morphological description given above shows clearly that the alfalfa-wilt fungus belongs to the section Elegans of the genus Fusarium. A comparison with illustrations and descriptions of other species of this section by Wollenweber (*23*, *24*),

Sherbakoff (*17*), and others convinced the writer that it resembled *F. oxysporum* Schlecht. emend. Wr. (*13, p. 139; 23*) so closely that it can best be referred to a variety of this species.[4]

Fusarium oxysporum var. *medicaginis* differs from *F. oxysporum* in pathogenicity and in having both longer and slightly wider spores. Its spores differ little in width from those of *F. oxysporum* var. *gladioli* and *F. oxysporum* var. *nicotianae* as described by Massey (*9*) and Johnson (*4*), respectively, but average somewhat longer.

PATHOGENICITY

The parasitism of *Fusarium oxysporum* var. *medicaginis* was proved by inoculating seed and plants and by infesting the soil with it.

On September 30, 1926, inoculations were made as follows:

(*a*) Sixteen 1-year-old alfalfa plants of the Kansas common variety that had always been grown in sterilized soil in the greenhouse were transplanted to sterilized soil and inoculated by pouring a spore suspension about their crowns. No wounds were made purposely, but rootlets were broken when the plants were transplanted.

(*b*) Sixteen plants of the same lot were transplanted and inoculated by inserting spores and hyphae beneath the bark through wounds.

(*c*) Six plants of the same lot were transplanted in a similar manner. Three of these were wounded like those described above but were not inoculated, and the other three were held unwounded except for the broken rootlets. The unwounded ones constituted the controls.

(*d*) Three pots of sterilized soil were sown with Kansas common seed. Two of these were inoculated by pouring a spore suspension over the seed before it was covered, and the third was held uninoculated as a control.

The first plant to show evidence of infection was pulled on November 1. Infection had been apparent for some time, as the disease was well advanced at this time. This plant is shown in Figure 1. Typical vascular browning was present both in the root and for some distance up the stem. The Fusarium was recovered from the internal brown tissue, studied in culture, and later used for further inoculation tests with positive results. On November 15 infection was evident in 12 of the 15 plants (1 plant did not survive transplanting) inoculated by inserting the inoculum into wounds. On December 10, when the plants were taken up and examined, various amounts of vascular browning were found in both the roots and stems in all but 1 plant, and the causal fungus was recovered from them all. Hence a total of 14 out of 15 plants, or 93.3 per cent, became infected. There was no evidence of infection in any of the controls. On November 15, 10 of the 14 plants (2 plants did not survive transplanting) inoculated with a spore suspension (*a*) showed unmistakable symptoms of the disease. Two more, making a total of 12 out of 14, or 85.7 per cent, became infected later and the fungus was recovered from all of them. Although infection became evident a little sooner when the inoculum was inserted into wounds, the ultimate amount of infection was nearly the same.

Infection in the seedlings (*d*) was first definitely proved to have taken place on November 26, although some plants had died pre-

[4] The writer is indebted to Dr. C. D. Sherbakoff, who after examining cultures of the fungus agreed with him that the fungus might well be made a variety of *Fusarium oxysporum* Schlecht. emend. Wr.

viously, supposedly from damping off but probably from wilt. Isolations were made from two wilted plants on this date and the causal organism recovered. The leaves of the affected plants turned yellow and then brown, and death resulted. This phase of the experiment was discontinued January 5, 1927, at which time 17 and 40 per cent, respectively, of the seedlings in the two inoculated pots were infected, and the causal fungus was recovered from them. At this time four plants in the uninoculated control pot also showed symptoms of a similar nature, and the fungus was recovered from three of them. These pots had stood near one another for more than two months, and no doubt some inoculum had been splashed from the inoculated pots into the control one by watering.

This experiment shows that infection can be produced in 1-year-old plants as well as in seedlings either by inserting the fungus into wounds or by infesting the soil. Infection appeared first in about a month, and affected plants were frequently entirely dead in six weeks. Symptoms similar to those evident in the field are produced under greenhouse conditions.

On February 1, 1927, plants of Kansas common alfalfa grown in the field from seed sown in August were brought to the greenhouse and transplanted into sterilized soil. Part of these plants were inoculated by inserting hyphae and spores into wounds in the taproot just below the crown and part by pouring a spore suspension into the soil about them. The fungus used for the inoculations was a single-spore culture of the fungus used in the experiment detailed above. Only 5 to 10 per cent of the plants in this test became infected, a slightly higher percentage occurring in those plants inoculated in wounds. This test was run largely during the winter and early spring months, and it has been observed since that only a small percentage of infection takes place during the winter months, whereas 75 to 100 per cent will occur during the late spring, summer, or autumn months. For example, on October 12, 1927, an experiment was begun in which this same strain of the fungus was inoculated into 10 plants, all of which became infected before December 12, when the experiment was discontinued. None of the controls became infected.

A culture of the Fusarium obtained from one of the plants infected in the first experiment cited above was used for a parasitism test made May 18, 1927. The plants used in this case were 9 months old and had grown in the field until two months prior to their inoculation, when they had been set in pots in the greenhouse. The tops were cut back, the soil was removed from the crowns and the upper parts of the taproots, and the inoculum was inserted beneath the bark of the taproot through wounds. Two pots each containing five plants were used for the inoculations, and a like number used as controls were injured, but not inoculated. All but two of the inoculated plants, or 80 per cent, became infected, while the controls remained healthy. The fungus was recovered from the diseased tissue and its identity determined.

Many more inoculation tests have been made with these and other isolations of this fungus over a period of one and one-half years, and usually a large percentage of infection resulted. However, it is believed that the tests detailed are sufficient to prove that this fungus is parasitic to alfalfa.

Since the alfalfa is so closely related to *Fusarium oxysporum*, infection experiments were conducted in which 10 alfalfa plants were inoculated with *F. oxysporum* and 10 young potato plants were inoculated with the Fusarium from alfalfa. In no case did any infection result. This test, although not carried out on a very large scale, indicates that the Fusarium from alfalfa differs parasitically from the one from potato. Since the fungus (*F. hyperoxysporum*) that causes stem rot of the sweet potato is so closely related to *F. oxysporum*, the parasitism of the Fusarium from alfalfa was also tested on sweet potato, but with negative results.

Alfalfa is used regularly in rotation with potatoes in Kansas, and although there is a varying amount of Fusarium wilt in the potatoes each year, none has ever been found in alfalfa in that State. Furthermore, as yet there is no evidence that the wilt of alfalfa occurs in any of the Northern States, in many of which both alfalfa and potatoes are used in rotation. Since the Fusarium from alfalfa seems to have such a limited distribution and *F. oxysporum* is so widely distributed it seems certain that they are at least parasitically two different organisms.

LIFE HISTORY

Little is known regarding the life history of *Fusarium oxysporum* var. *medicaginis*. So far as the writer has observed, the disease produced by it is present in about the same amount throughout the growing season. No doubt the causal organism is spread from one plant to another largely by the soil water. Having come in contact with a healthy plant, it apparently can enter through wounds or directly through the epidermis, especially of small rootlets. No experiments have been conducted to prove definitely that the fungus can enter the roots except through wounds, but this is indicated by the fact that the seedlings growing in soil that was sterilized and then infested become infected readily. The fungus often enters the taproot by way of small lateral roots. Frequently small rootlets having a brown color have been followed to the larger roots or the taproot and the infection thus traced to the larger roots, from which the fungus was isolated. After reaching the main roots from the rootlets the fungus may grow up or down within the vascular system. In several cases observed the vascular discoloration was more pronounced toward the top, indicating perhaps that at least in some instances the fungus makes more rapid progress upward.

Once the fungus has gained entrance to the main taproot, symptoms of the disease may appear in the tops in about a month, although it may take much longer. The fungus passes from the root into the stems, in which a conspicuous browning of the vascular region, often extending upward for several inches, is produced. After gradually spreading throughout the taproot and into the rootlets, the fungus finally causes the entire woody cylinders of the roots of small plants to turn dark in color and eventually kills them. The roots decay and the fungus is liberated. Plants grown on this infested soil become infected and thus the disease continues to spread.

CONTROL

No experiments have been conducted with a view to determining control measures. Observations made on some of Westover's fertilizer plots at West Point, Miss., did not indicate that lime or super-

phosphate (acid phosphate) had any effect on the prevalence of the disease.

Likewise the disease could be found in practically every variety of alfalfa grown in Westover's trials, although in many instances very few diseased plants were seen. Kansas common, Grimm, and Hairy Peruvian varieties have been inoculated in greenhouse tests and appear to be about equally susceptible.

How long the fungus can live in the soil is not known. Judging from the knowledge of other Fusaria of this type, no doubt a rather long rotation will be necessary to eliminate this source of infection.

SUMMARY

A disease of alfalfa in every way similar to the Fusarium-wilt diseases of many other plants is herein described. The disease is known to occur only in Mississippi, although plants received from California appeared to have a very similar and probably the same disease. Because of its limited distribution the disease is not of very great economic importance at the present time. However, it is a factor in thinning out the stands of alfalfa in northeastern Mississippi, where as many as 15 per cent of infected plants have been found in a field, and no soil or climatic factors that would prevent the spread of this disease to other regions are known.

The leaves of affected plants turn yellow, the tips of the stems frequently wilt, and the plants eventually die. Frequently one or more stems die while the rest remain healthy for a longer time. The vascular region of diseased plants, especially of the taproot, is some shade of brown, usually ranging from cinnamon brown to mummy brown.

This Fusarium wilt resembles bacterial wilt due to *Aplanobacter insidiosum* L. McC. to some extent but is readily distinguished from it.

The causal organism is described as *Fusarium oxysporum* var. *medicaginis*, n. var. It differs from *F. oxysporum* Schlecht. emend. Wr. chiefly in parasitism and spore size. It also seems to have a much more limited distribution than *F. oxysporum*. Its morphological and cultural characters are described in detail.

No control measures have been worked out.

LITERATURE CITED

(1) ARNAUD, G.
1910. UNE NOUVELLE MALADIE DE LA LUZERNE (MALADIE ROUGE). Prog. Agr. et Vitic. 54: 517–519, illus.

(2) BROWN, J. G., and GIBSON, F.
[1922]. PLANT PATHOLOGY. Ariz. Agr. Expt. Sta. Ann. Rpt. (1921-22) 33: 238–248, illus.

(3) COTTAM, W. P.
1921. A "DRY ROT" DISEASE OF ALFALFA ROOTS CAUSED BY A FUSARIUM. Phytopathology 11: 383.

(4) JOHNSON, J.
1921. FUSARIUM-WILT OF TOBACCO. Jour. Agr. Research 20: 515–536, illus.

(5) JONES, F. R.
1925. A NEW BACTERIAL DISEASE OF ALFALFA. Phytopathology 15: [243]–244.

(6) ——— and McCULLOCH, L.
1926. A BACTERIAL WILT AND ROOT ROT OF ALFALFA CAUSED BY APLANOBACTER INSIDIOSUM L. M'C. Jour. Agr. Research 33: 493–521, illus.

(7) McCallum, W. B.
1907. VEGETABLE PHYSIOLOGY AND PATHOLOGY. Ariz. Agr. Expt. Sta. Ann. Rpt. (1906–07) 18: [230]–232.

(8) ———
1908. PLANT PHYSIOLOGY AND PATHOLOGY. Ariz. Agr. Expt. Sta. Ann. Rpt. (1907–08) 19: [357]–361.

(9) Massey, L. M.
1926. FUSARIUM ROT OF GLADIOLUS CORMS. Phytopathology 16: 509–523, illus.

(10) Piper, C. V.
1924. FORAGE PLANTS AND THEIR CULTURE. Rev. ed., 671 p., illus. New York.

(11) Ridgway, R.
1912. COLOR STANDARDS AND COLOR NOMENCLATURE. 43 p., illus. Washington, D. C.

(12) Robbins, W. J., and Scott, I. T.
1926. [REPORT OF THE DEPARTMENT OF BOTANY.] Missouri Agr. Expt. Sta. Bul. 236: 44–45.

(13) Schlechtendal, D. F. L. de
1824. FLORA BEROLINENSIS. PARS SECUNDA: CRYPTOGAMIA. 284 p. Berolini.

(14) Scott, I. T.
1926. A STUDY OF CERTAIN FUSARIAL DISEASES OF PLANTS. Missouri Agr. Expt. Sta. Bul. 244: 30–31.

(15) Selby, A. D.
1910. A BRIEF HANDBOOK OF THE DISEASES OF CULTIVATED PLANTS IN OHIO. Ohio Agr. Expt. Sta. Bul. 214, p. 307–456, illus.

(16) ——— and Manns, T. F.
1909. STUDIES IN DISEASES OF CEREALS AND GRASSES. Ohio Agr. Expt. Sta. Bul. 203, p. 187–236, illus.

(17) Sherbakoff, C. D.
1915. FUSARIA OF POTATOES. N. Y. Cornell Agr. Expt. Sta. Mem. 6, p. 87–270, illus.

(18) Tehon, L. R.
1923. A SUMMARY OF THE PLANT DISEASE SITUATION IN 1922 WITH RESPECT TO THE CROPS OF ILLINOIS. Ill. State Acad. Sci. Trans. 16: 246–258.

(19) ———
1924. A PRELIMINARY REPORT ON THE OCCURRENCE AND DISTRIBUTION OF THE COMMON BACTERIAL AND FUNGOUS DISEASES OF CROP PLANTS IN ILLINOIS. Ill. Nat. Hist. Survey Bul. 15: [173]–325, illus.

(20) Weimer, J. L.
1927. OBSERVATIONS ON SOME ALFALFA ROOT TROUBLES. U. S. Dept. Agr. Circ. 425, 10 p., illus.

(21) ———
1927. A WILT DISEASE OF ALFALFA CAUSED BY FUSARIUM SP. Phytopathology 17: 337–338.

(22) Weniger, W.
1923. DISEASES OF GRAIN AND FORAGE CROPS IN NORTH DAKOTA. N. Dak. Agr. Expt. Sta. Bul. 166, 92 p., illus.

(23) Wollenweber, H. W.
1913. STUDIES ON THE FUSARIUM PROBLEM. Phytopathology 3: [24]–50, illus.

(24) ———
1917. FUSARIA AUTOGRAPHICE DELINEATA. Ann. Mycol. 15: 1–56.

THE INFLUENCE OF ENVIRONMENTAL FACTORS ON PIGMENT PATTERNS IN VARIETIES OF COMMON BEANS [1]

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INTRODUCTION

The failure to appreciate the rôle played by environment in the development of seed-coat pigments was most forcibly illustrated when the soy bean suddenly became an important crop in the Corn Belt. Some time passed before agronomists came to appreciate the fact that in a study of pigmentation environmental conditions must be considered as well as heredity; but no doubt it is now generally understood that not all mottling is the result of hereditary factors.

During the course of rather extensive experiments with mottling in soy beans (*2*),[2] the senior writer became interested in the general applicability of the same studies to various other leguminous plants and in particular to certain varieties of the common bean (*Phaseolus vulgaris*).

Thirteen years ago Pearl and Surface (*3*) made a careful study of the market situation with regard to varieties of common beans sold for baking purposes, particularly the Old Fashioned Yellow Eye and the Improved Yellow Eye varieties. The preference for a bean of a particular pattern as described at that time is very interesting in the light of the information now available. Had the variability due to environmental influences been better understood it is possible that the market demands might in many cases have been less exacting.

The production of seed-coat pigments forms a complicated study and the chemical and physiological processes involved are none too well understood at the present time, but the studies here reported throw some light on the rôle played by environmental factors and will perhaps be of some practical significance.

VARIETIES USED

During the course of two years' work (1926 and 1927) the following varieties of beans were studied: Old Fashioned Yellow Eye, Small Yellow Eye, Golden Wax, and Golden Carmine.

The color patterns of these varieties are shown in Figure 1, where the different classes represent artificial standards for convenience in statistical comparisons. The first three varieties are eyed types with a background of opaque white. The color patterns of the Old Fashioned Yellow Eye and the Small Yellow Eye are yellow and that of the Golden Wax is a mottled purple. The Golden Carmine is an entirely

[1] Received for publication July 14, 1928; issued November, 1928. This paper is No. 185 of the Biological Laboratory, Maine Agricultural Experiment Station, and No. 92 of the Department of Genetics, Wisconsin Agricultural Experiment Station. The work here recorded was begun at the Wisconsin station by the senior author under the supervision of R. A. Brink, but the present report is largely the result of the efforts of Mrs. Burgess, who has taken charge of the cooperative work at Monmouth, Me., and of C. R. Burnham, who has carried on the tests at Madison, Wis.

[2] Reference is made by number (italic) to "Literature cited," p. 442.

different type with peculiar red streaks on a somewhat yellowish pink background.

The Old Fashioned Yellow Eye has had a most interesting history in the bean-growing districts of Maine (*3*). The typical color pattern (see Maine-grown beans, fig. 2) of this variety is within itself a source of attraction, and it is natural that a prejudice should have become established against beans that depart too widely from this type. Some difficulty has been experienced in always securing this uniform

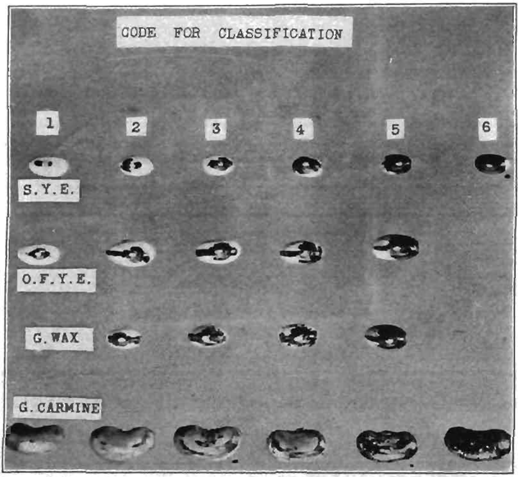

FIG. 1.—Arbitrary pattern classes of bean pigmentation adopted by the writers to facilitate the statistical analysis of their results. Class 2 shows the typical patterns of the Old Fashioned Yellow Eye variety; classes 3 and 4 are more typical of the Golden Wax. For the first three varieties classes 5 and 6 show what extreme modifications may be brought about by simply changing the environmental conditions. For the Golden Carmine variety the situation is somewhat different. Classes 1 to 4 are typical of the variety, and classes 5 and 6 occur very sporadically and apparently quite independent of environmental conditions. About three-fourths natural size. Photographed by H. C. White

pattern, but nevertheless it is quite definite in outline and is much more uniform than that of many other varieties.

The Old Fashioned Yellow Eye variety has been studied extensively at the Maine station (*6*, *7*), and Karl Sax has considerable unpublished data on the variability of size of bean and of the color pattern. Although many of these studies have been somewhat incidental to the present subject, they have helped to establish familiarity with the influence of hereditary factors on the amount of pigment formed. Progeny records within pure lines constitute the best information at hand, and records kept by Sax and Burgess give a pretty definite idea of the possibility of selecting for more

uniformity in this variety. Slight differences no doubt exist between different lines and it has been suspected that hereditary influences control the variability on a single plant to some extent, but the progress of these studies has been handicapped because of the large amount of variability due to environment.

The Small Yellow Eye is not a commercial variety, but is the result of a selection made by one of the writers (Burgess) in 1923. It is an offspring from a hybrid between the Improved Yellow Eye and a white variety (*4*, *5*), and it is one of the very few segregates

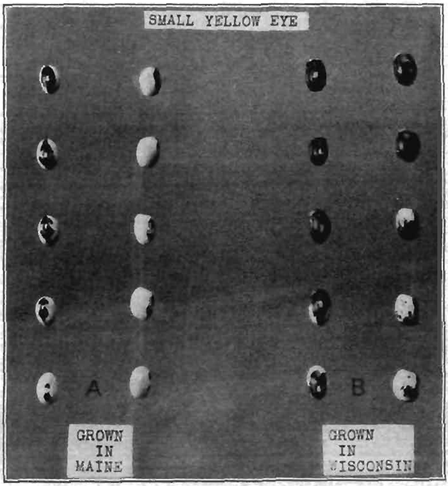

FIG. 2.—Extreme color pattern differences in Small Yellow Eye beans grown under different environmental conditions: A, Beans from plants grown on sandy soil at Monmouth, Me.; B, beans from plants grown on fertile soil at Madison, Wis., spaced 3 feet apart. As here shown, the color pattern of the Small Yellow Eye variety was very readily influenced by environment. Plants spaced 3 feet apart on rich soil displayed the extreme amount of pigment. Difference in climate seemed to be of minor importance, since dark beans were obtained at Wisconsin only when the plants were spaced 3 feet apart and grown on rich soil. Three-fourths natural size. Photographed by H. C. White

that approached the Old Fashioned Yellow Eye in pattern type with any degree of exactness. Experience has proved, however, that it is somewhat more variable than the Old Fashioned Yellow Eye.

The Golden Wax and Golden Carmine seeds were selected at random from commercial varieties that were being grown at the Wisconsin station. Occasional dark colored beans are produced by the Golden Carmine variety, but these occur only sporadically, as if due to some peculiar change in the cells of somatic tissue rather than to either environment or normal modes of inheritance.

TESTING THE EFFECT OF ENVIRONMENT

A study of the results obtained with the four varieties of beans grown in different regions and under different soil conditions gives a vivid picture of the effect produced by environment; and for the Small Yellow Eye variety, at least, the results are striking.

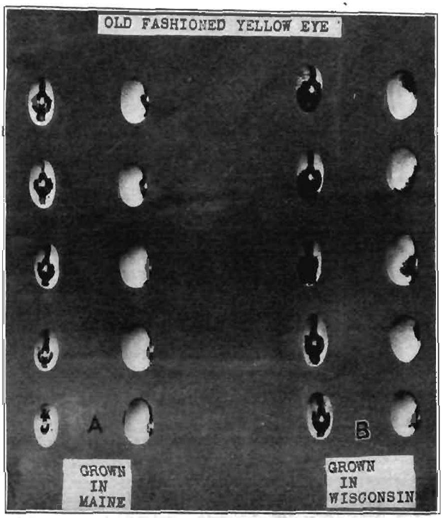

FIG. 3.—A very stable color pattern changed by environmental conditions: A, Old Fashioned Yellow Eye beans from plants grown on sandy soil at Monmouth, Me.; B, beans of the same variety from plants grown on fertile soil at Madison, Wis., spaced 3 feet apart. The Old Fashioned Yellow Eye beans were markedly affected by the rich soil of Wisconsin, but the difference was not nearly so striking as in the case of the Small Yellow Eye variety. This variety might well be considered remarkable for its uniformity of pattern. Three-fourths natural size. Photographed by H. C. White

The environmental conditions under which the beans were grown in 1926 were as follows:

Madison, Wis.	sandy soil	plants 1 inch apart in 3-foot rows.
		plants 3 feet apart in 3-foot rows.
	very rich loam soil	plants 2 inches apart in 3-foot rows.
		plants 3 feet apart in 3-foot rows.
Highmoor Farm, Monmouth, Me.	sandy soil	plants 1 inch apart in 3-foot rows.
		plants 2 feet apart in 3-foot rows.
	very rich loam soil	plants 2 inches apart in 3-foot rows.
		plants 2 feet apart in 3-foot rows.
Aroostook Farm, Presque Isle, Me.	plants 2 feet apart (for the Old Fashioned Yellow Eye and Small Yellow Eye varieties).	

The varieties tested were not necessarily pure lines, but before any samples were taken a composite lot of seed was mixed thoroughly and subsequent samples were made from this common lot so that heriditary factors should be comparable for each environment.

Environment seems to have had little effect on the Golden Wax and Golden Carmine varieties, but undoubtedly it exerted considerable effect on the Old Fashioned Yellow Eye and even more on the Small Yellow Eye. Figures 2 and 3 give very good illustrations (not exaggerated) of the difference between the beans grown on sandy soil at Monmouth, Me., and those grown on very rich soil at Madison, Wis. The tremendous increase in pigment due to the rich soil of Wisconsin is clearly apparent.

NUMERICAL INTERPRETATION OF RESULTS

To put the results in numerical form, six arbitrary classes were made according to the amount of pigment present on each bean. (See fig. 1.) It must be kept in mind that these artificial classes intergrade to some extent, so that a statistical treatment may be somewhat misleading except where the differenees are very large. The χ^2 test is not held to be a true measure of significance because the personal error in classification alone is an extremely variable factor; but it does help to visualize the data. The χ^2 values for all of the tabulations presented here ($\chi^2=40$ is the lowest) represent infinite odds according to Elderton's (*1*) tables, but since the personal error also affects the value of χ^2 no attempt should be made to distinguish fine differences. Furthermore the extreme contrasts are the most important, and these hardly need statistical interpretation.

The most obvious contrast is between the Small Yellow Eye beans grown on rich soil at Madison, Wis., and those grown on unfertilized soil at Aroostook Farm, Presque Isle, Me., as shown in Table 1.

TABLE 1.—*Effect of fertility of soil on pigmentation of Small Yellow Eye beans*

Environment	Per cent of total number of seeds observed in class—						Total number of seeds
	1	2	3	4	5	6	
Rich soil, Madison, Wis., plants 3 feet apart	1.2	6.4	16.7	27.6	37.2	10.9	952
Very infertile soil, Presque Isle, Me., plants 2 feet apart	41.6	5.9	35.3	17.1	------	------	269

No statistical analysis is needed to portray the significance of the figures shown in Table 1, but if the χ^2 test is applied on the assumption that the Maine-grown beans are the result of chance variation from the Wisconsin beans, $\chi^2=3{,}895$, and the probability is so infinitesimally small that the certainty of the difference can not be questioned.[3]

The distance of spacing was also an important factor, especially on the rich soil at Madison. The figures observed for the Small Yellow Eye and the Old Fashioned Yellow Eye varieties are shown in Tables 2 and 3.

[3] χ^2 has been calculated from the actual frequencies. The total number of frequencies in this instance is 269 and the comparison is between the actual frequencies for the beans grown in Maine and a theoretical population (also of 269 frequencies) distributed in accord with the classification of the beans grown in Wisconsin.

TABLE 2.—*Effect of thickness of stand on pigmentation of Small Yellow Eye beans*

Environment	Per cent of total number of seeds in class— 1	2	3	4	5	6	Total number of seeds
Plants 3 feet apart on rich soil at Madison, Wis.	1.2	6.4	16.7	27.6	37.2	10.9	952
Plants 2 inches apart on rich soil at Madison, Wis.	39.4	24.6	25.4	10.6	-------	-------	264

$\chi^2=3,478$

TABLE 3.—*Effect of fertility of soil and thickness of stand on pigmentation of Old Fashioned Yellow Eye beans*

Environment	Per cent of total number of seeds in class— 1	2	3	4	5	6	Total number of seeds	
Rich soil, Madison, Wis., plants 3 feet apart	-------	46.0	35.5	12.0	6.5	-------	722	χ^2=infinite.
Sandy soil, Monmouth, Me., plants 2 feet apart	23.6	47.3	29.2	-------	-------	-------	641	
Plants 3 feet apart on rich soil at Madison, Wis.	-------	46.0	35.5	12.0	6.5	-------	722	$\chi^2=40$.
Plants 2 inches apart on rich soil at Madison, Wis.	-------	55.4	38.8	4.4	1.4	-------	363	

Differences in the Old Fashioned Yellow Eye are very significant when the beans grown in Wisconsin on rich soil are compared with those grown in Maine. The effect of distance of spacing, however, was less striking than in the case of the Small Yellow Eye.

The effect of these factors on the pigmentation of the Golden Wax variety is shown in Table 4. This variety seems to be naturally somewhat variable, and although the differences brought about by environment are probably significant, the contrast is not nearly so great as in the Yellow Eye variety.

TABLE 4.—*Effect of fertility of soil and thickness of stand on pigmentation of Golden Wax beans*

Environment	Per cent of total number of seeds in class— 1	2	3	4	5	6	Total number of seeds	
Rich soil, Madison Wis., plants 3 feet apart	-------	1.8	17.6	31.6	48.9	-------	272	$\chi^2=216$.
Sandy soil, Monmouth, Me., plants 2 feet apart	-------	1.8	46.5	34.9	16.8	-------	720	
Plants 3 feet apart on rich soil at Madison, Wis.	-------	1.8	17.6	31.6	48.9	-------	272	$\chi^2=223$.
Plants 2 inches apart on rich soil at Madison, Wis.	-------	5.0	28.6	47.8	18.6	-------	161	

A tabulation for the Golden Carmine variety showed no definite effect due to environment. The occurrence of the very dark seeds (fig. 1, classes 5 and 6) was relatively infrequent and seemed to be quite independent of environmental influences.

Although the 1926 results were very convincing and proved practically conclusive that the rich soil at Madison was responsible for the greater quantity of pigment present in the Small Yellow Eye and the Old Fashioned Yellow Eye varieties, it was thought well to

confirm these results by an additional test, and this was carried out during the season of 1927. The dark colored Small Yellow Eye beans produced on the rich soil at Madison in 1926 and beans of the typical varietal patterns grown on the sandy soil at Monmouth, Me., in 1926 were planted on the same soil at Monmouth, Me. The object of this test was to determine whether or not the dark beans would show a tendency to perpetuate their kind. The results are given in Table 5.

From this table it is seen that the highly colored Wisconsin seed failed to reproduce even as much pigment as the Maine-grown seed. It is reasonable to suppose, therefore, that the extreme effects which were visible in 1926 were due entirely to environmental influences.

TABLE 5.—*Inheritance of pigmentation in beans grown in 1927 at Monmouth, Me., from highly colored and from normal seed produced under different environmental conditions*

Source and pigmentation of seed	Per cent of total number of seeds in class—						Total number of seeds
	1	2	3	4	5	6	
Highly colored seed from rich soil at Madison, Wis., 1926	11.1	31.8	47.5	8.8	0.8	0.1	1,808
Normal seed from sandy soil at Monmouth, Me., 1926	7.8	18.4	54.4	19.1	0.3		1,580

$\chi^2=318$.

INTERPRETATION OF ENVIRONMENTAL INFLUENCES

What the controlling influences are that affect pigment formation in a seed coat is a difficult question and the reader is referred to the previous studies which attempt to interpret certain observations for soy beans (2). Undoubtedly the accumulation of sugars is a very important factor because of the glucosidal nature of the pigments. But the combination of environmental factors responsible for an accumulation of sugars may be very complex. A particular feature of the plant's environment naturally produces effects according to the combination of other environmental factors and the physiological condition within the plant must be considered at all times.

The most important environmental factors that affect the production of seed-coat pigments are probably related to the nourishment of the plant. A rich soil has usually increased the production of pigment in seed coats. Spacing the plants a considerable distance apart also seems to have the same effect. It is difficult always to duplicate experiments, however, and it seems that the nature of maturity is one of the most important things to be considered. Prolonged vegetative growth may upset all previous expectations, and it is believed that plants of the runner type (7) which ripen unevenly are more likely to show variability within individuals.

For the maximum development of pigment a combination of factors is necessary, and unfortunately these factors are rather poorly understood. On certain types of soil it makes little difference how the plants are spaced. In fact, in certain instances, results contradictory to the general rule have been observed. For instance, during the summer of 1927 somewhat more pigment was formed in Old Fashioned Yellow Eye and Small Yellow Eye beans at Highmoor Farm spaced 2 inches apart than in those spaced 3 feet apart. Probably there

was some difference in soil fertility, but whatever may have been the cause it is outside the realm of the present discussion. The main point to consider here is that environmental factors are important in determining the amount of seed-coat pigment that is produced.

The results here recorded are very similar to those that have many times been found in the course of the soy-bean studies. It is evident that a large number of environmental influences indirectly affect the internal condition of the plant, such as soil fertility, weather conditions, soil moisture, and distance between plants. With this in mind it is easy to understand how one limiting factor may be responsible for the difference between lightly colored and highly colored beans in one instance while the same factor may be insignificant in another instance. For further progress along this line of investigation a more intimate knowledge of the physiological conditions within the plant is essential.

SUMMARY

Environmental conditions are described which have been found to be of great importance in determining color patterns in common beans. Four varieties of beans were tested in different types of soil in Maine and Wisconsin.

Plants spaced 3 feet apart on rich soil at Madison, Wis., developed a striking amount of pigment. That this was not the result of climatic differences is apparent from the fact that dark beans were obtained at Wisconsin only when the plants were spaced 3 feet apart and grown on rich soil.

To determine whether the dark beans would tend to perpetuate their kind, dark colored Small Yellow Eye beans produced in 1926 on the rich soil at Madison and beans of the typical varietal patterns grown on sandy soil at Monmouth, Me., were planted on the same soil at Monmouth in 1927. In these experiments the highly colored Wisconsin seed failed to produce even as much pigment as the Maine-grown seed. It is therefore believed that the extraordinary amount of pigment present in the Wisconsin seed in 1926 was due entirely to environmental influences.

LITERATURE CITED

(1) Elderton, W. P.
[1906]. Frequency-curves and correlation. 172 p., illus. London.

(2) Owen, F. V.
1927. Hereditary and environmental factors that produce mottling in soy beans. Jour. Agr. Research 34: 559–587, illus.

(3) Pearl, R., and Surface, F. M.
1915. Studies on bean breeding. I. Standard types of Yellow Eye beans. Maine Agr. Expt. Sta. Bul. 239, p. [161]–176, illus.

(4) Sax, K.
1923. The association of size differences with seed-coat pattern and pigmentation in Phaseolus vulgaris. Genetics 8: 552–560.

(5) ———
1926. Quantitative inheritance in Phaseolus. Jour. Agr. Research 33: 349–354.

(6) ——— and McPhee, H. C.
1923. Color factors in bean hybrids. Jour. Heredity 14: 205–208, illus.

(7) Surface, F. M.
1916. A note on the inheritance of eye pattern in beans and its relation to type of vine. Amer. Nat. 50: 577–586, illus.

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